Terrestrial Monitoring

CHAPTER 6

Cynthia L. Conrado
Nicholas A. Bertoldo
Richard A. Brown
Lisa Paterson
S. Ring Peterson
Jim Woollett

Introduction

Lawrence Livermore National Laboratory monitors several aspects of the terrestrial environment. LLNL measures the radioactivity present in soil, sediment, vegetation, and wine, and the absorbed gamma radiation dose at ground level receptors from terrestrial and atmospheric sources. In addition, LLNL monitors the abundance, distribution, and ecological requirements of plant and wildlife species as part of compliance activities and research programs.

The LLNL terrestrial radioactivity monitoring program is designed to measure any changes in environmental levels of radioactivity and to evaluate any increase in radioactivity that might have resulted from LLNL operations. All monitoring activity follows U.S. Department of Energy (DOE) guidance. Monitoring on site or in the vicinity of the Livermore site or Site 300 detects radioactivity released from LLNL that may contribute to radiological dose to the public or to biota; monitoring at distant locations not impacted by LLNL operations detects naturally occurring background radiation.

Terrestrial pathways from LLNL operations leading to potential radiological dose to the public include resuspension of soils, infiltration of constituents of runoff water through arroyos to groundwater, ingestion of locally grown foodstuffs, and external exposure to contaminated surfaces and radioactivity in air. Potential ingestion doses are calculated from measured concentrations in vegetation and wine; doses from exposure to ground level external radiation are obtained directly from thermoluminescent dosimeters (TLDs) deployed for environmental radiation monitoring. Potential dose to biota (see Chapter 7) is calculated using a simple screening model that requires knowledge of radionuclide concentrations in soils, sediments, and surface water.

Surface soil samples are analyzed for plutonium and gamma-emitting radionuclides. Gamma-emitting radionuclides in surface soils include uranium isotopes, which are used to provide data about the natural occurrence of uranium as well as data about the effects of explosive tests at Site 300, some of which contain depleted uranium. Other gamma-emitting, naturally occurring nuclides (potassium-40 and thorium-232) provide additional data about local background conditions, and the long-lived fission product cesium-137 provides information on global fallout from historical nuclear weapons testing. In addition, soils at Site 300 are analyzed for beryllium, a potentially toxic metal used there. With the addition of tritium, a similar suite of nuclides is analyzed in the sediments. Concentrations in soil to be taken from the vadose zone (the region below the land surface where the soil pores are only partially filled with water) are compared with de minimis concentrations for tritium and background concentrations for metals. Vegetation and wine samples are measured for tritium alone because tritium is the only nuclide released from LLNL that can be measured in these products. Cosmic radiation accounts for about half the absorbed gamma dose measured by the TLDs; naturally occurring isotopes of the uranium-thorium-actinium decay series provide the dose from natural background radiation found in the earth's crust. By characterizing the background radiation, LLNL can determine what, if any, excess dose can be attributed to laboratory operations.

Surface soils near the Livermore site and Site 300 have been sampled since 1971. Around the Livermore site, sediments (from selected arroyos and other drainage areas) and vadose zone soils have been sampled since 1988 and 1996, respectively; sampling of sediments or vadose zone soils is not warranted at Site 300. LLNL has been monitoring tritium in vegetation since 1966 and has performed routine vegetation sampling on and around the Livermore site and Site 300 since 1971. External radiation has been monitored around the Livermore site since 1973 and around Site 300 since 1988.

Sampling for all media is conducted according to written, standardized procedures summarized in the *Environmental Monitoring Plan* (Woods 2005).

LLNL also monitors wildlife and plants at the Livermore site and Site 300, and carries out research relevant to the protection of rare plants and animals. Some monitoring and research programs are required by existing permits, while additional monitoring programs are designed to track the distribution and abundance of rare species. In addition, baseline surveys are conducted to determine distribution of special status species on LLNL property. Monitoring and research of biota on LLNL property is conducted to ensure compliance with requirements of the U.S. Endangered Species Act, the California Endangered Species Act, the Eagle Protection Act, the Migratory Bird Treaty Act, and the California Native Plant Protection Act as they pertain to endangered or threatened species and other special status species, their habitats, and designated critical habitats that exist at the LLNL sites.

Soil and Sediment Monitoring

There are 6 soil and 4 sediment sampling locations on LLNL's Livermore site (**Figure 6-1**); 13 soil sampling locations in the Livermore Valley, including 6 at the Livermore Water Reclamation Plant (LWRP) (**Figure 6-2**); and 14 soil sampling locations at Site 300 (**Figure 6-3**). The locations were selected to represent background concentrations (distant locations unlikely to be affected by LLNL operations) as well as areas where there is the potential to be affected by LLNL operations. Areas with known contaminants, such as the LWRP and areas around explosives tests areas at Site 300, are also sampled.

Surface sediment and vadose zone soils are collected from selected arroyos and other drainage areas at and around the Livermore site; these locations (**Figure 6-1**) largely coincide with selected storm water sampling locations (see Chapter 5). Soils in the vadose zone are collected in arroyo channels at the Livermore site as part of the Ground Water Protection Management Program. Infiltration of natural runoff through arroyo channels is a significant source of groundwater recharge, accounting for an estimated 42% of resupply for the entire Livermore Valley groundwater basin (Thorpe et al. 1990). The collocation of sampling for sediment and storm water runoff facilitates comparison of analytical results.

Surface soil samples are collected from the top 5 cm of soil because aerial deposition is the primary pathway for potential contamination, and resuspension of materials from the surface into the air is the primary exposure pathway to nearby human populations. Two 1-m squares are chosen from which to collect the sample. Each sample is a composite consisting of 10 subsamples that are collected at the corners and the center of each square with an 8.25 cm diameter stainless steel core sampler. Surface sediment samples are collected in a similar manner. Ten subsamples, 5-cm deep, are collected at 1-m intervals along a transect of the arroyo or drainage channel. At one of the subsample locations, a 15-cm deep sample is acquired for tritium analysis; this deeper sample is necessary to obtain sufficient water in the sample for tritium analysis. Vadose zone samples are collected at the same location as the tritium subsample. A hand auger is used to collect a 30- to 45-cm deep sample for metals analysis, and an electric drive coring device is used to collect a sample 45- to 65-cm deep for analysis for polychlorinated biphenyls (PCBs).

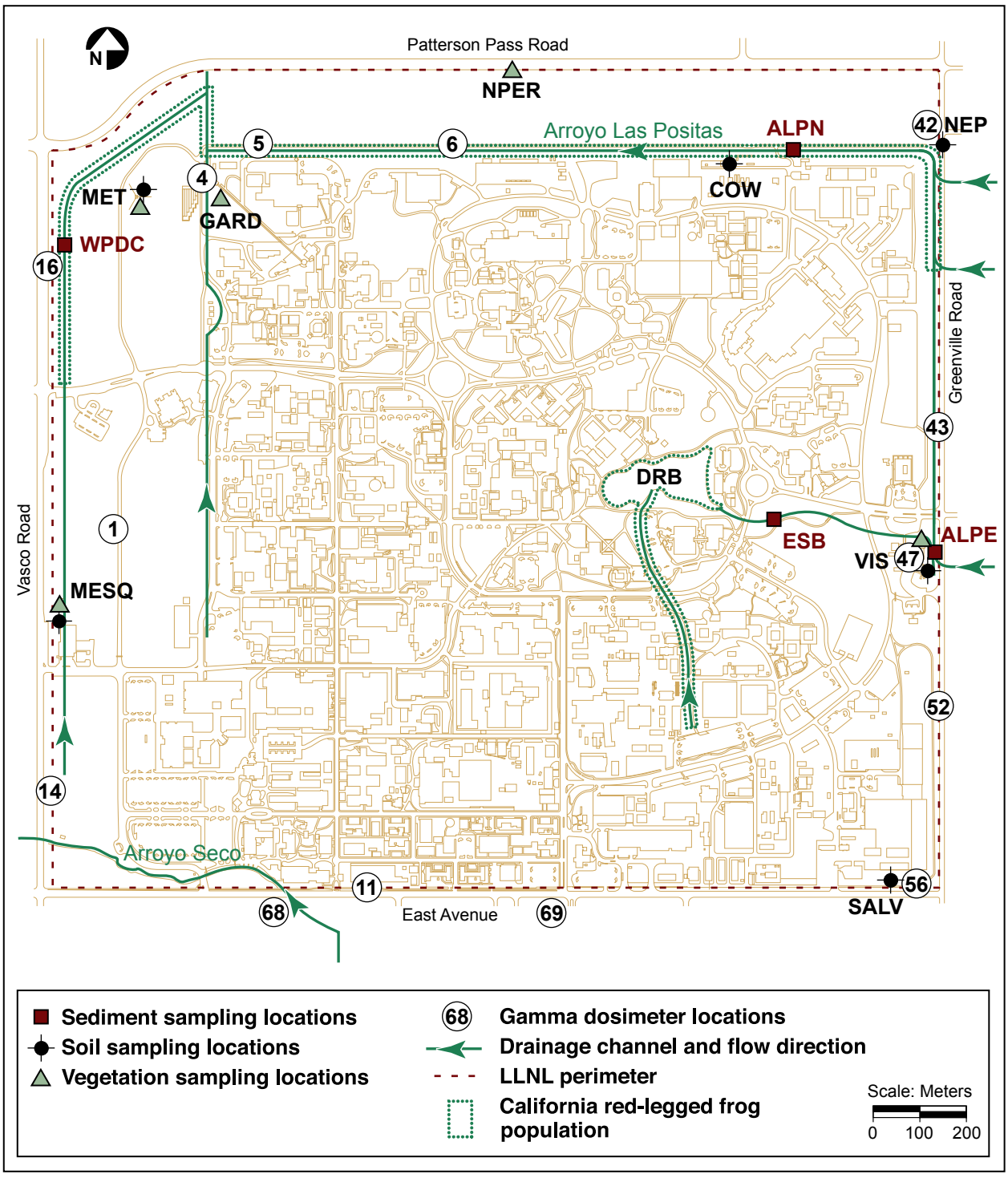


Figure 6-1. Sampling locations and California red-legged frog populations, Livermore site, 2005

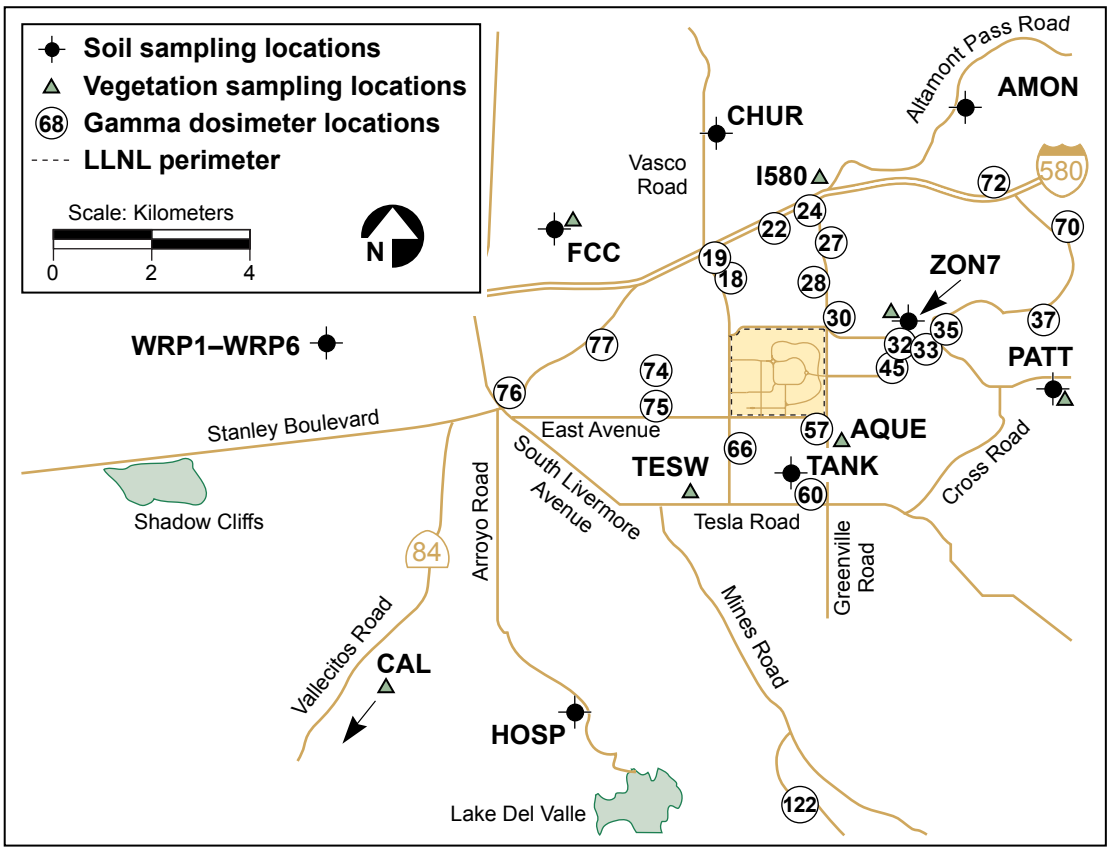


Figure 6-2. Sampling locations, Livermore Valley, 2005

In 2005, surface soil samples in the Livermore Valley were analyzed for plutonium and gamma-emitting radionuclides. Samples from Site 300 were analyzed for gamma-emitting radionuclides and beryllium. Annual sediment samples collected at the Livermore site were analyzed for plutonium, gamma-emitting radionuclides, and tritium. Vadose zone samples were analyzed for total and soluble metals; one vadose zone location was analyzed for PCBs.

Prior to radiochemical analysis, surface soil and sediment samples are dried, sieved, ground, and homogenized. The plutonium content of a 100-g sample aliquot is determined by alpha spectrometry. Other sample aliquots (300-g) are analyzed by gamma spectrometry using a high-purity germanium (HPGe) detector for 47 radionuclides, including fission products, activation products from neutron interactions on steel, actinides, and natural products. The 10-g subsamples for beryllium analyses are analyzed by atomic emission spectrometry.

Vadose zone soil samples are analyzed by standard EPA methods. In 2005, as in the previous five years, a vadose zone soil sample from location ESB (**Figure 6-1**) was also analyzed for PCBs.

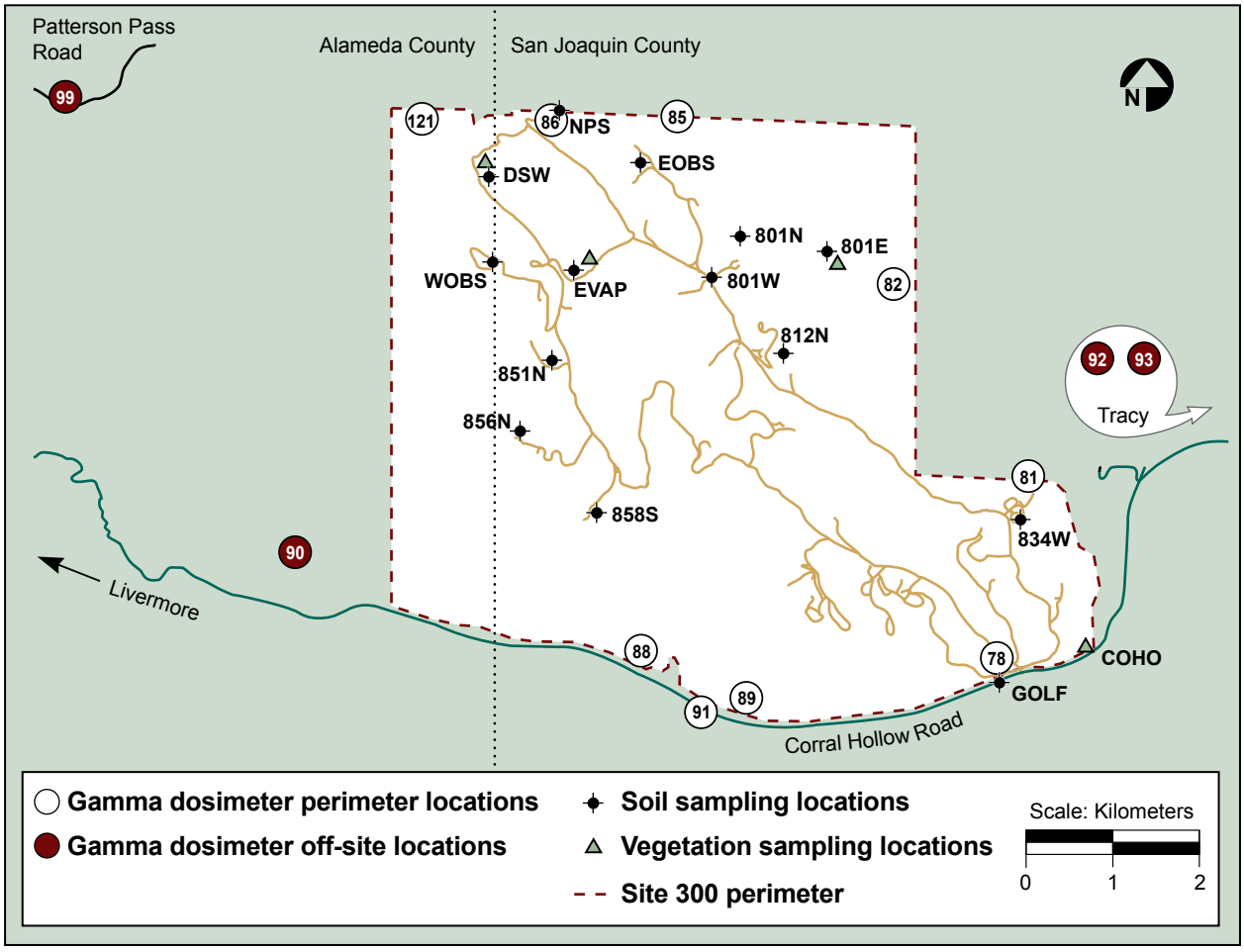


Figure 6-3. Sampling locations at Site 300 and off-site, 2005

Radiological Monitoring Results

Tables 6-1 through **6-3** present data on the concentrations of plutonium-238 and plutonium-239+240 in the Livermore Valley surface soils and sediments; data for americium-241, which is only detected at LWRP; and data for tritium, which is only measured in surface sediments. Data for cesium-137, potassium-40, thorium-232, uranium-235, and uranium-238 in surface soils from the Livermore Valley sampling locations are included in the file "Ch6 Soil" provided on the report CD.

Table 6-1. Plutonium activity concentrations in Livermore Valley soil, 2005

Location	Plutonium-238 (mBq/dry g)	Plutonium-239+240 (mBq/dry g)
L-AMON-SO	0.0077 ± 0.0024	0.054 ± 0.010
L-CHUR-SO	0.0085 ± 0.0030	0.12 ± 0.021
L-COW-SO	0.0065 ± 0.0034	0.023 ± 0.0065
L-FCC-SO	0.0032 ± 0.0015	0.069 ± 0.013
L-HOSP-SO	0.0060 ± 0.0022	0.028 ± 0.0060
L-MESQ-SO	0.0018 ± 0.0013	0.028 ± 0.0060
L-MET-SO	0.0020 ± 0.0013	0.040 ± 0.0078
L-NEP-SO	0.0031 ± 0.0020	0.055 ± 0.011
L-PATT-SO	0.0028 ± 0.0016	0.036 ± 0.0077
L-SALV-SO	0.0079± 0.0027	0.094 ± 0.017
L-TANK-SO	0.0057± 0.0023	0.11 ± 0.020
L-VIS-SO	0.023 ± 0.0052	0.39 ± 0.063
L-ZON7-SO	0.0078 ± 0.0026	0.020 ± 0.0048
Median	**0.0060**	**0.054**
IQR[a]	**0.0047**	**0.066**
Maximum	**0.023**	**0.39**

Note: Radioactivities are reported as the measured concentration and either an uncertainty (±2σ counting error) or as being less than or equal to the detection limit. If the concentration is less than or equal to the uncertainty or the detection limit, the result is considered to be a nondetection. See Chapter 9.

a IQR = Interquartile range

Table 6-2. Plutonium and americium activity concentrations in LWRP soil, 2005

Location	Plutonium-238 (mBq/dry g)	Plutonium-239+240 (mBq/dry g)	Americium-241 (mBq/dry g)
L-WRP1-SO	0.44 ± 0.071	8.2 ± 1.3	5.6 ± 1.4
L-WRP2-SO	0.26 ± 0.043	4.9 ± 0.77	<1.2
L-WRP3-SO	0.026 ± 0.0055	0.47 ± 0.075	<0.53
L-WRP4-SO	0.044 ± 0.0088	0.64 ± 0.10	<0.67
L-WRP5-SO	0.11 ± 0.019	2.0 ± 0.32	<2.1
L-WRP6-SO	0.12 ± 0.021	2.3 ± 0.36	<1.1
Median	**0.12**	**2.2**	**<1.2**
IQR[a]	**0.16**	**3.3**	**—[b]**
Maximum	**0.44**	**8.2**	**5.6**

Note: Radioactivities are reported as the measured concentration and either an uncertainty (±2σ counting error) or as being less than or equal to the detection limit. If the concentration is less than or equal to the uncertainty or the detection limit, the result is considered to be a nondetection. See Chapter 9.

a IQR = Interquartile range

b Interquartile range not calculated because of high incidence of nondetections.

Table 6-3. Plutonium and tritium activity concentrations in surface sediment, 2005

Location	Plutonium-238 (mBq/dry g)	Plutonium-239+240 (mBq/dry g)	Tritium (Bq/L)
L-ALPE-SD	0.0028 ± 0.0013	0.032 ± 0.0064	0.74 ± 2.1
L-ALPN-SD	0.0031 ± 0.0014	0.013 ± 0.0033	5.6 ± 2.2
L-ESB-SD	0.22 ± 0.036	1.8 ± 0.29	15 ± 2.4
L-WPDC-SD	0.0013 ± 0.0015	0.0066 ± 0.0029	1.4 ± 2.1
Median	**0.0030**	**0.023**	**3.5**
IQR[a]	**—[b]**	**—[b]**	**—[b]**
Maximum	**0.22**	**1.8**	**15**

Note: Radioactivities are reported as the measured concentration and either an uncertainty (±2σ counting error) or as being less than or equal to the detection limit. If the concentration is less than or equal to the uncertainty or the detection limit, the result is considered to be a nondetection. See Chapter 9.

a IQR = Interquartile range

b Interquartile range not calculated because of high incidence of nondetections

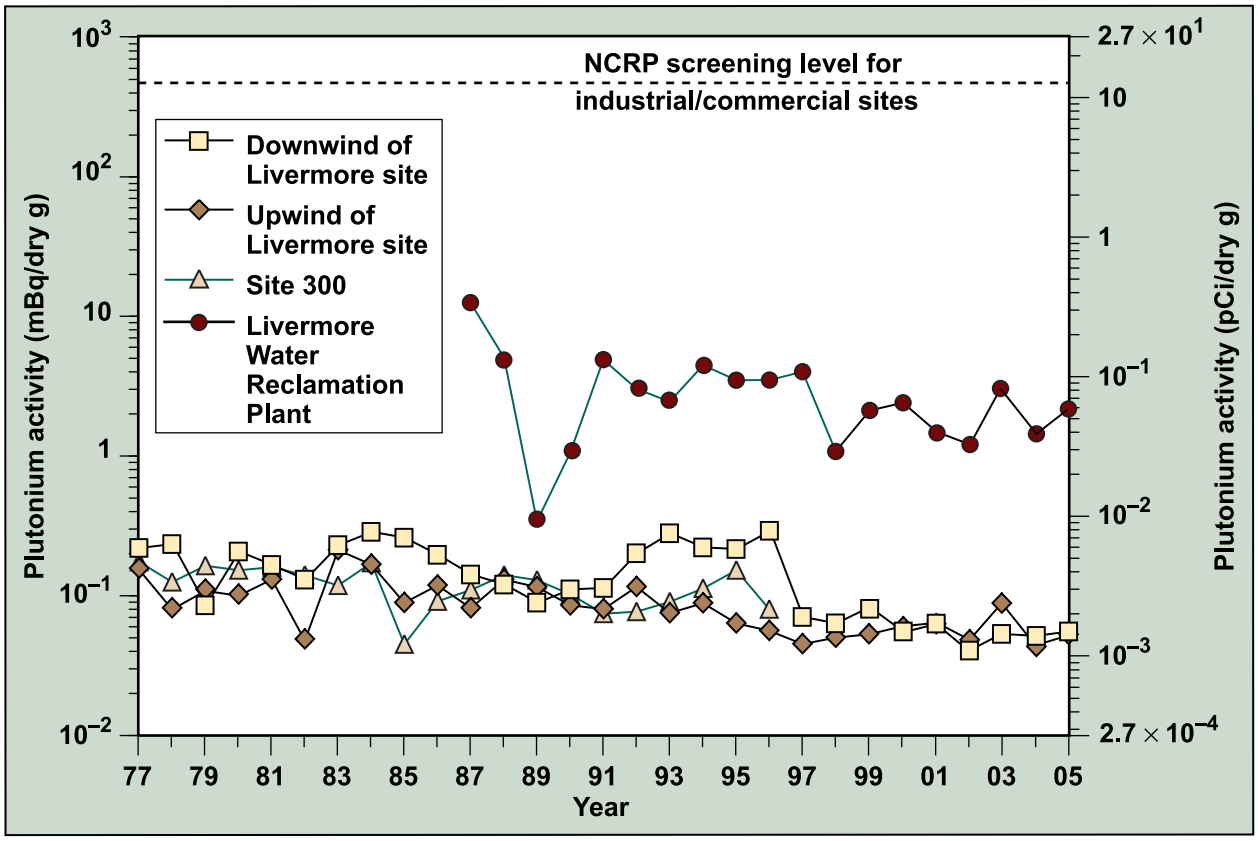
The concentrations and distributions of all observed radionuclides in soil for 2005 are within the ranges reported in previous years and generally reflect worldwide fallout and naturally occurring concentrations. Plutonium has, in the past, been detected at levels above background at VIS, a perimeter sampling location near the east boundary of the Livermore site. In 2005, the measured plutonium-239+240 value for VIS was 0.39 mBq/dry g (1.05×10^{-2} pCi/dry g), a value that is less than the 95% upper confidence level for the 95th percentile calculated for background data (i.e., 0.48 mBq/dry g [1.3×10^{-2} pCi/dry g]) (LLNL 1998, Appendix D). The slightly higher values at and near the Livermore site have been attributed to historic operations (Silver et al. 1974), including the operation of solar evaporators for plutonium-containing liquid waste in the southeast quadrant. LLNL ceased operating the solar evaporators in 1976 and no longer engages in any other open-air treatment of plutonium-containing waste.

A sediment sampling location, ESB, also shows the effects of historic operation of the solar evaporators; it is in the drainage area for the southeast quadrant at LLNL. The measured value for plutonium-239+240 at this location for 2005 was 1.8 mBq/dry g (4.9×10^{-2} pCi/dry g). The highest detected value for tritium, 15 Bq/L (407 pCi/L), was at location ESB, which is located downwind of the Tritium Facility. There was a slight increase in tritium emissions from the Tritium Facility in 2005, as described in Chapter 4. However, all tritium concentrations were within the range of previous data. LLNL will continue to evaluate tritium in sediment.

Elevated levels of plutonium-239+240 (resulting from an estimated 1.2×10^{9} Bq [32 mCi] plutonium release to the sanitary sewer in 1967 and earlier releases) were again detected at LWRP sampling locations. In

addition, americium-241 was detected in one LWRP sample; it was most likely caused by the natural radiological decay of the trace concentrations of plutonium-241 that were present in the releases to the sewer.

Historical median plutonium-239+240 concentrations in soil in the Livermore Valley upwind and downwind of the center of the LLNL Livermore site and at LWRP are shown in **Figure 6-4**. Livermore Valley upwind concentrations have remained relatively constant since monitoring began and generally are indicative of worldwide fallout. Greater variation can be noted over time in the downwind concentration data compared with the upwind concentration data. In 2005 the downwind location sites included VIS, PATT, NEP, COW, AMON, SALV, and ZON7. Notable variability in plutonium-239+240 is also seen in samples from LWRP. Because the plutonium-239+240 is likely to be present in discrete particles, the random presence or absence of the particles dominates the measured plutonium-239+240 in any given sample.



Note: Upwind and downwind designations are relative to the center of the Livermore site.
NCRP = National Council on Radiation Protection and Measurements

Figure 6-4. Median plutonium-239+240 activities in surface soils, 1977–2005

Table 6-4 presents data on the concentrations of uranium-235, uranium-238, and beryllium in soil from the Site 300 sampling locations; 2005 soils data for Site 300 for cesium-137, potassium-40, and thorium-232 are included in the file "Ch6 Soil" provided on the report CD. The concentrations and the distributions of all radionuclides observed in Site 300 soil for 2005 lie within the ranges reported in all years since monitoring began. At 10 of the 14 sampling locations, the ratio of uranium-235 to uranium-238 reflects the natural ratio of 0.7%. There is significant uncertainty in calculating the ratio, however, due to the difficulty of measuring low activities of uranium-238 by gamma spectrometry. The highest measured values for uranium-235 and uranium-238 and the lowest ratio of uranium-235 to uranium-238 for 2005 occurred at 812N. The uranium-235 to uranium-238 ratio in this sample equals the ratio for depleted uranium (i.e., 0.002). Such values at Site 300 result from the use of depleted uranium in explosive experiments.

Nonradiological Monitoring Results

Analytical results for metals are compared with site-specific natural background concentrations for metals. (See the file "Ch6 Soil" provided on the report CD for the background concentrations for both the Livermore site and Site 300 and analytical results for metals.)

All metals concentrations at the Livermore site were within site background, with the exception of total and soluble zinc at location ESB. Livermore site groundwater surveillance monitoring (see Chapter 5) will determine the impacts, if any, on site groundwater. Since 2000 when surveillance for PCBs at this location began, Aroclor 1260 (a PCB) has been detected at location ESB. In 2005, it was again detected at location ESB at a concentration of 1.7 mg/kg. The presence of PCBs suggests that this sample represents residual low-level contamination from the 1984 excavation of the former East Traffic Circle landfill (see Chapter 5). The detected concentrations are below the federal and state hazardous waste limits.

Beryllium results for soils at Site 300 (**Table 6-4**) were within the ranges reported since sampling began in 1991. The highest value, 5.6 mg/kg, was found at B812, which is an area that has been used for explosives testing. This value is much less than the 110 mg/kg detected at B812 in 2003. These differing results reflect the particulate nature of the contamination.

Table 6-4. Uranium and beryllium concentrations in Site 300 soil, 2005

Location	Uranium-235[a] (µg/dry g)	Uranium-238[b] (µg/dry g)	U235/U238 ratio[c]	Beryllium (mg/kg)
3-801E-SO	0.019 ± 0.0083	1.7 ± 0.81	0.011 ± 0.0072	<0.5
3-801N-SO	0.041 ± 0.011	9.7 ± 2.1	0.0042 ± 0.0015	0.51
3-801W-SO	0.024 ± 0.0083	5.4 ± 2.6	0.0044 ± 0.0026	<0.5
3-812N-SO	0.23 ± 0.017	130 ± 9.1	0.0018 ± 0.00018	5.6
3-834W-SO	0.023 ± 0.015	1.7 ± 1.9	—[d]	<0.5
3-851N-SO	0.026 ± 0.013	2.7 ± 1.5	0.0096 ± 0.0072	0.57
3-856N-SO	0.020 ± 0.0084	2.4 ± 3.0	—[d]	<0.5
3-858S-SO	0.026 ± 0.013	2.6 ± 1.6	0.010 ± 0.0079	<0.5
3-DSW-SO	0.022 ± 0.0091	3.1 ± 0.94	0.0071 ± 0.0036	<0.5
3-EOBS-SO	0.020 ± 0.0089	1.6 ± 1.9	—[d]	<0.5
3-EVAP-SO	0.038 ± 0.012	5.9 ± 2.1	0.0064 ± 0.0031	<0.5
3-GOLF-SO	0.020 ± 0.0091	1.1 ± 1.6	—[d]	<0.5
3-NPS-SO	0.020 ± 0.011	3.2 ± 2.0	0.0063 ± 0.0052	<0.5
3-WOBS-SO	0.052 ± 0.010	19 ± 2.6	0.0027 ± 0.00065	<2.5
Median	**0.024**	**2.9**	**0.0064**	**<0.5**
IQR[e]	**0.015**	**3.9**	**0.0047**	**—[f]**
Maximum	**0.23**	**130**	**0.011**	**5.6**

Note: Radioactivities are reported as the measured concentration and either an uncertainty (±2σ counting error) or as being less than or equal to the detection limit. If the concentration is less than or equal to the uncertainty or the detection limit, the result is considered to be a nondetection. See Chapter 9.

a Uranium-235 activities can be determined by multiplying the mass concentration provided in the table in µg/dry g by specific activity of uranium-235 (i.e., 0.080 Bq/µg or 2.15 pCi/µg).

b Uranium-238 activities can be determined by multiplying the mass concentration provided in the table in µg/dry g by specific activity of uranium-238 (i.e., 0.01245 Bq/µg or 0.3367 pCi/µg).

c Ratio of uranium-235 to uranium-238 is 0.00725 for naturally occurring uranium and 0.002 for depleted uranium.

d Not calculated because of uranium-235 or uranium-238 nondetections.

e IQR = Interquartile range

f Interquartile range not calculated because of high incidence of nondetections.

Environmental Impact on Soil and Sediment

Livermore Site

Routine surface soil, sediment, and vadose zone soil sample analyses indicate that the impact of LLNL operations on these media in 2005 has not changed from previous years and remains insignificant. Most analytes of interest or concern were detected at background concentrations or in trace amounts, or could not be measured above detection limits.

The highest value of 8.2 mBq/dry g (0.22 pCi/dry g) for plutonium-239+240 measured at LWRP is 2% of the National Council on Radiation Protection and Measurements (NCRP) recommended screening limit of 470 mBq/g (12.7 pCi/g) for property used for commercial purposes (NCRP 1999). Regression analysis of the annual medians of the upwind and downwind data groups shows a slight decrease in plutonium-239+240 values with time.

Over the years, LLNL has frequently investigated the presence of radionuclides in local soils. Several of the studies are listed in **Table 6-5**. These studies have consistently shown that the concentrations of radionuclides in local soils are below levels of health concern.

Table 6-5. Special soil and sediment studies

Year	Subject[a]	Reference
1971–1972	Radionuclides in Livermore Valley soil	Gudiksen et al. 1972; Gudiksen et al. 1973
1973	Radionuclides in San Joaquin Valley soil	Silver et al. 1974
1974	Soil study of southeast quadrant of Livermore site	Silver et al. 1975
1976	Evaluation of the Use of Sludge Containing Plutonium as a Soil Conditioner for Food Crops	Myers et al. 1976
1977	Sediments from LLNL to the San Francisco Bay	Silver et al. 1978
1980	Plutonium in soils downwind of the Livermore site	Toy et al. 1981
1990	195 samples taken in southeast quadrant for study	Gallegos et al. 1992
1991	Drainage channels and storm drains studied	Gallegos 1991
1993	EPA studies southeast quadrant	Gallegos et al. 1994
1993	Historic data reviewed	Gallegos 1993
1995	LLNL, EPA, and DHS sample soils at Big Trees Park	MacQueen 1995
1999	Summary of results of 1998 sampling at Big Trees Park	Gallegos et al. 1999
2000	Health Consultation, Lawrence Livermore National Laboratory, Big Trees Park 1998 Sampling	ATSDR 2000
2002	Livermore Big Trees Park:1998 Results	MacQueen et al. 2002
2003	ATSDR Public Health Assessment Plutonium 239 in Sewage Sludge Used as a Soil or Soil Amendment in the Livermore Community	ATSDR 2003

a See Acronyms and Abbreviations for list of acronyms.

Site 300

The concentrations of radionuclides and beryllium observed in soil samples collected at Site 300 are within the range of previous data and are generally representative of background or naturally occurring levels. The uranium-235/uranium-238 ratios that are indicative of depleted uranium occur near firing tables at Buildings 801 and 812. They result from the fraction of the firing table operations that disperse depleted uranium. The uranium-238 concentrations are below the NCRP recommended screening level for commercial sites of 313 µg/g (3.9 Bq/g or 105 pCi/g). Historically, some measured concentrations of uranium-238 near Building 812 have been greater than the screening level. A Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) remedial investigation is underway at the Building 812 firing table area to define the nature and extent of contamination.

Vegetation and Foodstuff Monitoring

Vegetation sampling locations at the Livermore site (**Figure 6-1**) and in the Livermore Valley (**Figure 6-2**) are divided into three groups (Near, Intermediate, and Far) for comparison. Tritium from LLNL operations may be detected at the Near and Intermediate locations depending upon wind direction and the magnitude of the releases. Near locations (AQUE, GARD, MESQ, NPER, MET, and VIS) are onsite or within 1 km of the LLNL site perimeter; Intermediate locations in the Livermore Valley (I580, PATT, TESW, and ZON7) are greater than 1 and less than 5 km from the LLNL perimeter. Far locations are highly unlikely to be affected by LLNL operations; one background location (CAL) is more than 25 km distant, and the other (FCC) is about 5 km from the Livermore site but generally upwind.

There are four monitoring locations for vegetation at Site 300 (**Figure 6-3**). Vegetation at locations DSW and EVAP exhibit variable tritium concentrations due to uptake of contaminated groundwater by roots. At the two other locations, 801E and COHO, the only potential source of tritium uptake is the atmosphere.

Wines for sampling in 2005 were purchased from a supermarket in Livermore. Wines represent the Livermore Valley, two regions of California, and the Rhone Valley in France.

Water is extracted from vegetation by freeze-drying and counted for tritiated water (HTO) using liquid scintillation techniques. Both HTO and organically bound tritium (OBT) are detected in wine using helium-3 mass spectrometry, but the relative fractions of each are not determined.

Vegetation Monitoring Results

All concentrations of tritium in Livermore vegetation for 2005 are shown in **Table 6-6.** The highest mean tritium concentration in vegetation for 2005 was at the Near location MET, although concentrations at MESQ and NPER were quite similar. High concentrations of 12 Bq (320 pCi)/L at MET in the third quarter and 13 Bq (350 pCi)/L at MESQ in the fourth quarter may have been due to the presence of a transportainer containing tritiated equipment (see air tritium discussion in Chapter 4).

Median values for each set of sampling locations are graphed in **Figure 6-5** to show the trend in tritium concentrations in vegetation since 1972. Median concentrations at the Far and Intermediate locations have been below the detection limits for several years. Since 2003, the median concentrations for Near locations have also been below detection limits. The lower limit of detection (LLD) of scintillation counting has varied over the years, and a comparison of results based on the recent mean value of the LLD of about 2.0 Bq/L (54 pCi/L) eliminates some variability arising from uncertain counting statistics at these low levels. Detectable concentrations were higher in 2005 than in 2004 primarily due to higher releases from the Tritium Facility. The highest concentration in plant water in 2005 was just 1.8% of the drinking water standard (740 Bq or 20,000 pCi/L). Median concentrations in vegetation have decreased noticeably since 1989 (**Figure 6-5**); at MET, the only onsite location that was sampled in 1989, the annual median concentration of tritium in plant water in 2005 was sixteen times lower than it was in 1989.

Between 1996 and 2004, concentrations in needles from a pine tree growing near Building 292 were reported in the Environmental Report. Because the tree was rooted in groundwater having elevated concentrations of tritium, its annual median concentrations were on average more than 20 times higher than those of Near vegetation. Sampling was not carried out on this tree in 2005 because it was no longer necessary to treat it as a minor source of tritium for compliance dose calculations (Harrach et al. 2005) and because it was infested with red turpentine bark beetles. In August 2005, a large limb broke off the tree, and in January 2006 the tree was removed. Analysis of a representative core of the tree revealed concentrations of HTO and OBT of 0.0807 Bq/g (2.18 pCi/g) and 0.455 Bq/g (12.3 pCi/g) respectively. Because the concentration in the tree was greater than the 0.185 Bq/g (5 pCi/g) that can

be taken to the local landfill for disposal, the tree was treated as radioactive waste and moved to the Nevada Test Site.

Table 6-6. Quarterly concentrations of tritium in plant water (Bq/L) and mean annual ingestion doses, 2005

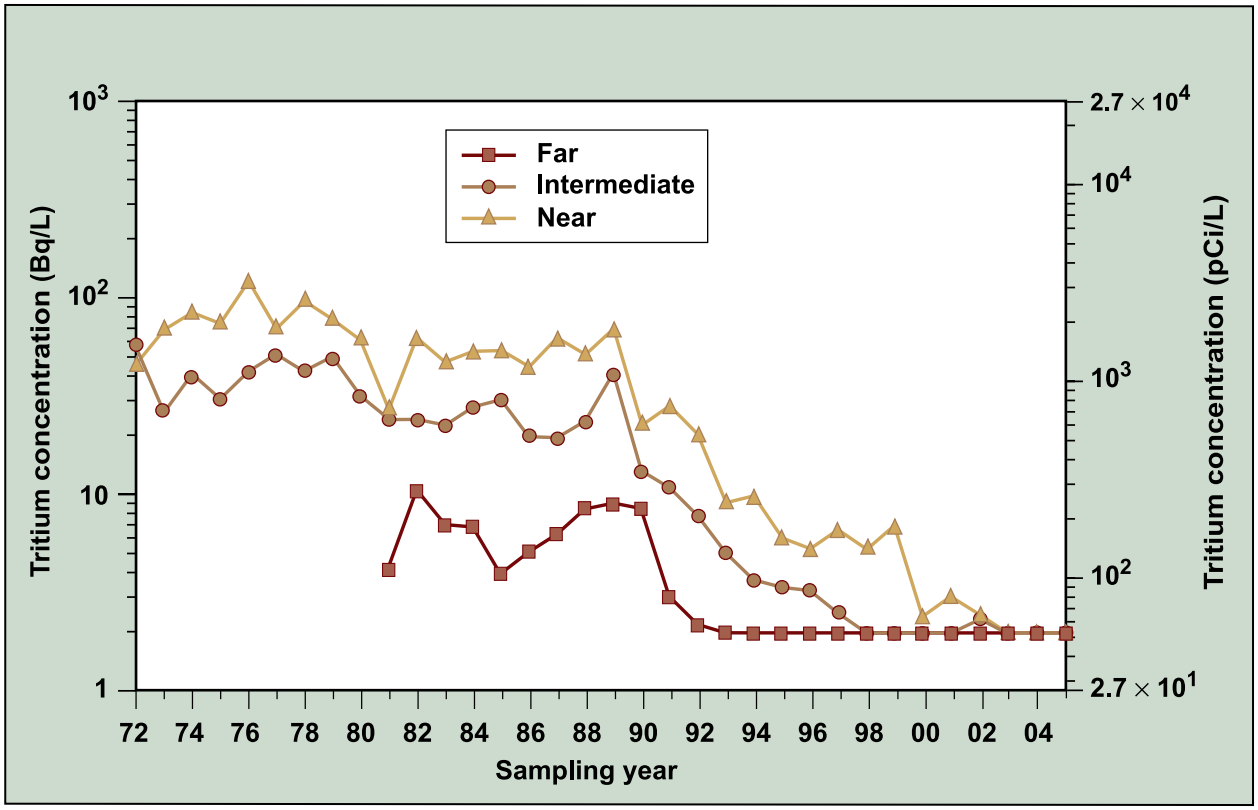
	First quarter	Second quarter	Third quarter	Fourth quarter	Median	Mean	Mean dose[a] (nSv/y)
Sampling locations within 1 km of the Livermore site perimeter							
AQUE	0.77 ± 1.4	–0.020 ± 1.7	0.93 ± 1.7	1.2 ± 2.3	0.85	0.72	< 10[b]
GARD	0.72 ± 1.4	0.34 ± 1.7	2.5 ± 1.8	9.3 ± 2.4	1.6	3.2	16
MESQ	1.2 ± 1.3	0.84 ± 1.8	4.5 ± 1.8	13 ± 2.5	2.9	4.9	24
MET	2.5 ± 1.5	1.3 ± 1.8	12 ± 2.0	5.2 ± 2.3	3.9	5.3	26
NPER	1.6 ± 1.4	3.2 ± 1.9	7.6 ± 1.9	6.3 ± 2.3	4.8	4.7	23
VIS	2.0 ± 1.4	0.21 ± 1.7	6.5 ± 1.9	0.75 ± 2.3	1.4	2.4	12
Sampling locations from 1 to less than 5 km from the Livermore site perimeter							
I580	1.1 ± 1.4	2.6 ± 1.8	2.2 ± 1.8	–0.0069 ± 2.2	1.7	1.5	< 10[b]
PATT	–0.39 ± 1.3	1.4 ± 1.8	0.63 ± 1.7	2.2 ± 2.3	1	0.96	< 10[b]
TESW	0.58 ± 1.3	0.83 ± 1.8	5.4 ± 1.8	–1.2 ± 2.2	0.71	1.4	< 10[b]
ZON7	0.43 ± 1.3	1.2 ± 1.8	2.3 ± 1.8	–1.9 ± 2.2	0.82	0.51	< 10[b]
Sampling locations more than 5 km from the Livermore site perimeter							
CAL	–0.92 ± 1.3	0.90 ± 1.8	0.084 ± 1.7	–0.46 ± 2.2	–0.19	–0.099	< 10[b]
FCC	–0.42 ± 1.3	0.75 ± 1.8	–0.38 ± 1.7	1.6 ± 2.3	0.19	0.39	< 10[b]
Sampling locations at Site 300							
COHO	–0.26 ± 1.2	1.1 ± 1.8	0.36 ± 1.7	1.5 ± 2.3	0.73	0.68	< 10[b]
801E	–1.0 ± 1.7	0.62 ± 1.8	0.68 ± 1.7	–1.2 ± 2.2	–0.19	–0.22	< 10[b]
DSW[c]	–0.20 ± 1.3	46 ± 3.1	5.5 ± 1.8	5.0 ± 2.4	5.3	14	69
EVAP[c]	0.20 ± 1.2	150 ± 4.9	150 ± 3.8	19 ± 2.6	85	80	390

Note: Radioactivities are reported as the measured concentration and an uncertainty (±2σ counting error). If the concentration is less than or equal to the uncertainty, the result is considered to be a nondetection. See Chapter 9.

a Ingestion dose is based on conservative assumptions that an adult's diet is exclusively vegetables with this tritium concentration, and that meat and milk are derived from livestock fed on grasses with the same concentration of tritium. See **Table 7-6**.

b When concentrations are less than the detection limit (about 2.0 Bq/L), doses can only be estimated as being less than the dose at that concentration.

c These plants are rooted in areas of known subsurface contamination.



Note: When median values are below the lower limit of detection (approximately 2.0 Bq/L [54 pCi/L]), values are plotted as 2.0 Bq/L to eliminate meaningless variability.

Figure 6-5. Median tritium concentrations in Livermore site and Livermore Valley plant water samples, 1972 to 2005

All samples at Site 300 locations 801E and COHO were below detection limits. Median concentrations at locations 801E and COHO have been at or below detection limits since 1991. Tritium concentrations in vegetation at DSW and EVAP have been erratic since 1983, with concentrations being either high or below the LLD, depending upon whether or not the roots were taking up contaminated groundwater. The median concentrations at DSW and EVAP for 2005 were somewhat higher than those in 2004. The highest concentration (150 Bq/L [4050 pCi/L]) was observed at EVAP.

Wine Monitoring Results

The mean concentration of tritium (1.6 Bq/L [43 pCi/L]) in Livermore Valley wines sampled in 2005 is nearly double the mean for 2004, but it is still below the LLD for liquid scintillation counting; California wines continue to reflect residual historical bomb fallout and cosmogenic tritium levels (**Table 6-7**). The concentrations in the Rhone Valley (France) wines, vinted in 2003, are comparable to those vinted in 2001 that were sampled in 2004 (**Figure 6-6**);

this is expected because the Rhone Valley is home to numerous nuclear reactors used for power production. The highest concentration in a Livermore Valley wine sampled in 2005 (2.7 Bq/L [73 pCi/L]) was from a wine made from grapes harvested in 2002.

Table 6-7. Tritium in retail wine (Bq/L), 2005[a]

Sample	Area of production		
	Livermore Valley	California	Europe
1	0.62 ± 0.2	0.34 ± 0.19	4.6 ± 0.5
2	0.92 ± 0.21	0.40 ± 0.19	5.3 ± 0.56
3	1.1 ± 0.22		
4	1.5 ± 0.24		
5	2.7 ± 0.33		
6	2.7 ± 0.33		
	Dose (nSv/y)[b]		
	2.7	0.40	5.2

Note: Radioactivities are reported here as the measured concentration and an uncertainty (±2σ counting error).

a Wines from a variety of vintages were purchased and analyzed for the 2005 sampling. Concentrations are those on January 20, 2006.

b This dose is calculated based on consumption of 52 L wine per year at maximum concentration (see Chapter 7). Doses account for contribution of OBT as well as of HTO.

Because only a small number of bottles of Livermore Valley, California, and European (Rhone Valley) wine were sampled in 2005 (**Table 6-7**), a statistical comparison cannot be made. However, it is clear that the Livermore Valley wine with the lowest concentration is indistinguishable from the two California wines. The tritium concentrations in the Rhone Valley wines sampled are distinctly higher than even the highest of the Livermore Valley wines sampled.

The Livermore Valley wines purchased in 2005 represent vintages from 2000 to 2003. Thus, to compare the effect of LLNL operations on local wines, concentrations at the time of laboratory analysis must be corrected for the radiological decay that has occurred since the approximate date of harvest. Decay-corrected concentrations of tritium in wine for the Livermore Valley, California, and Europe are shown in **Figure 6-6** for the years from 1991 to present. Concentrations are shown for all wines sampled. The concentration of tritium in rainfall at Portland, Oregon (IAEA/WMO 2004) is also shown to demonstrate the similarity between tritium concentrations in California wines and background tritium concentrations on the Pacific coast (no similar rainfall data exist for California).

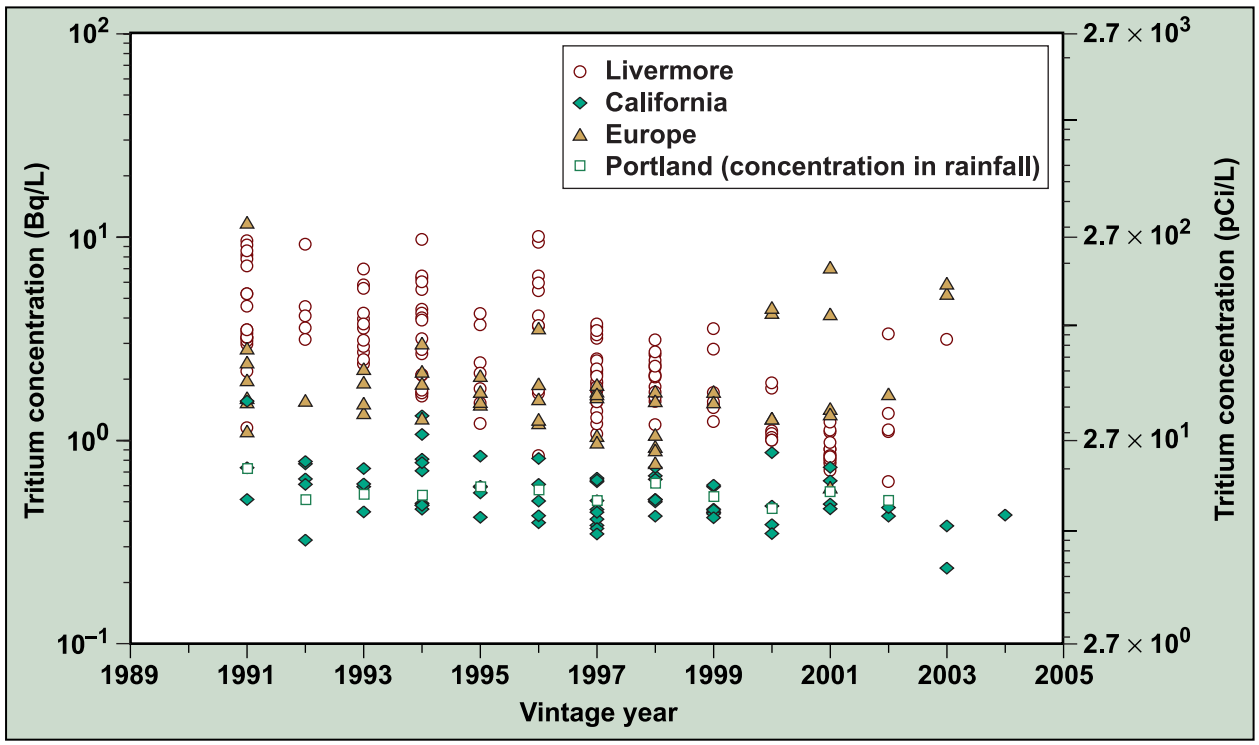


Figure 6-6. Tritium concentrations in all retail wines sampled since 1991 decay-corrected from the sampling year to the vintage year

Environmental Impact on Vegetation and Wine

Vegetation

Hypothetical annual ingestion doses for mean concentrations of tritium in vegetation are shown in **Table 6-6**. These doses were calculated for historical continuity using the transfer factors from **Table 7-6** based on U.S. Nuclear Regulatory Commission Regulatory Guide 1.109 (U.S. NRC 1977). All doses are estimated based on measured concentrations of HTO in vegetation and consequent dose from HTO ingestion. The hypothetical annual ingestion dose, based on highest observed mean HTO concentration in vegetation for 2005, was 26 nSv (2.6 µrem), which is essentially the same as the estimated dose in 2004.

Doses calculated based on Regulatory Guide 1.109 neglect the increased contribution from OBT. However, according to a conclusion by a panel of tritium experts, "the dose from OBT that is ingested in food may increase the dose attributed to tritium by not more than a factor of two, and in most cases by a factor much less than this." (ATSDR 2002). Thus, the maximum estimated ingestion dose from LLNL operations for 2005 is at most 52 nSv/y (5.2 µrem/y).

The estimated annual ingestion dose (52 nSv; 5.2 µrem) at the location with the highest mean air concentration for 2005, calculated from measured HTO concentrations in plant water and adjusted to account for dose from OBT, is about 1/58,000 of the average annual background dose in the United States from all natural sources and about 1/200 the dose from a panoramic dental x-ray. The ingestion dose is calculated on the assumption that all the vegetables, milk, and meat have concentrations that represent the location of the sampled vegetation. This is an improbable scenario because the average person lives farther from the Livermore site than the location of the highest vegetation concentrations and grows just a small fraction of total food ingested. Thus the likely potential dose received (see **Table 7-8**) will be considerably smaller than this already tiny dose.

Although the pine tree growing near Building 292 was disposed of at the Nevada Test Site, it posed no hazard to the public. Any inhalation dose to the public from the HTO released from the tree was taken into account by the tritium concentrations measured at the perimeter ambient air tritium monitors (see data table "at-ls" in file "Ch4 Ambient Air" on the report CD). If an individual could have eaten the wood of the entire tree, the ingestion dose would have been about 70 µSv[1] (7.0 mrem).

During 2005 at Site 300, no tritium was released to the atmosphere from LLNL operations. Consequently, vegetation concentrations were below detection limits except at locations of contaminated groundwater (see Chapter 8, "Remediation Activities and Monitoring Results" section). Contaminated groundwater resulting from past activities affects concentrations in vegetation at locations DSW and EVAP. The dose calculated from these elevated concentrations is entirely hypothetical, however, because neither people nor livestock ingest vegetation at Site 300. The mean annual ingestion dose for 2005 for location EVAP, which exhibited the higher concentrations of the two locations, would have been 390 nSv (39 µrem).

Wine

For Livermore Valley wines purchased in 2005, the highest concentration of tritium (2.7 Bq/L [73 pCi/L]) was just 0.36% of the Environmental Protection Agency's standard for maximal permissible levels of tritium in drinking water (740 Bq/L [20,000 pCi/L]). Drinking 1 L per day of the Livermore Valley wine with the highest concentration purchased in 2005 would have resulted in a dose of 19 nSv/y (1.9 µrem/y). A more realistic dose estimate, based on moderate drinking (1 L per week)[2] at the mean of the Livermore Valley wine concentrations (1.6 Bq/L [43 pCi/L]) would have been 1.6 nSv/y

[1] This was estimated using the dose coefficients compiled for Federal Guidance Report No. 13 (Eckermann et al. 1999).

[2] Moderate consumption is higher than the average consumption of wine in California (15.7 L/y) (Avalos 2005).

(0.16 µrem/y). Both doses explicitly account for the added contribution of OBT[3].

Local wineries are sufficiently distant from the Livermore site that tritium in wines can only be detected reliably using an ultra-sensitive method. The potential dose from drinking Livermore Valley wines in 2005, including the contribution of OBT, even at the high consumption rate of 1 L per day, would have been about 1/580 of a single dose from a panoramic dental x-ray.

Ambient Radiation Monitoring

Gamma radiation in the environment comes from two natural sources. The first source is the *terrestrial component*, which is caused by the radioactive decay of parent elements formed in the earth's crust 4.5 billion years ago (e.g., uranium-238, thorium-232, and potassium-40) and their respective daughter radiations. The second source is from the *cosmic component* of external radiation, which induces secondary radiations from interactions with atmospheric nuclei in the upper atmosphere. These cosmic interactions result in the production of meson, neutron, gamma, and electron radiations at the earth's surface (Eisenbud 1987).

LLNL's ambient radiation monitoring program is designed to distinguish any LLNL operational contribution from these natural sources by sampling a significant number of locations to validate the large natural background.

Methods and Reporting

Exposure to external radiation is measured by correlating the interaction of ionizing energy with its effect on matter which absorbs it. The roentgen (R) was adopted as the special unit of exposure dose by the International Commission on Radiological Units in 1956 and is defined as the charge required to ionize a given volume of air (2.58×10^{-4} coulombs per kilogram of air) (Attix and Roesch 1968).

It is this equivalency that is used to determine the quantity of ambient radiation measured by portable thermoluminescent dosimeters (TLDs) placed in the surrounding community. LLNL uses the Panasonic UD-814AS1 TLD, which contains three crystal elements of thallium-activated calcium sulfate ($CaSO_4$).

[3] Dose from wine is calculated by summing the dose from HTO in the water fraction of wine and the dose from OBT in the organic fraction of wine. Dose coefficients for HTO and OBT are those of the International Commission on Radiation Protection (1996). The organic component of wine (estimated from grape juice) increases the dose by 6% over what it would be had wine no organic fraction.

As the TLD absorbs ionizing energy, electron–hole pairs are created in the crystal lattice, trapping this absorbed energy in the crystal's excited state. The absorbed energy in the TLD crystal is released in the form of light emission upon heating the TLD to extreme temperature. This light emission, which is proportional to the TLD absorbed dose, is then collected by a photomultiplier tube and compared to its glow curve, as it is termed, which is calibrated to a known standard of cesium-137 gamma energy of 662 keV. The result of the TLD exposure is then reported in the International System (SI) unit of sievert (Sv) from the calculated dose in mR (1×10^{-3} R).

In order to compare LLNL dose contributions with the natural background, the TLD placement locations are divided into three groups:

- Livermore site locations—shown in **Figure 6-1**
- Livermore Valley locations—shown in **Figure 6-2**
- Site 300 and the local offsite vicinity, and sites in the city of Tracy—shown in **Figure 6-3**

In addition, the State of California Radiological Health Branch maintains several collocated TLD sample sites around the LLNL perimeter and Livermore Valley for independent monitoring comparison.

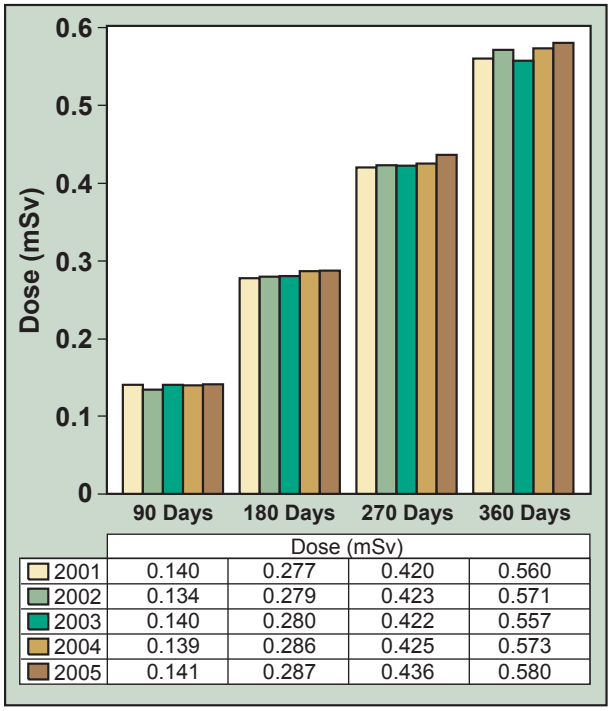
In order to obtain a true representation of the local site exposure and determine any dose contribution from LLNL operations, an annual environmental monitoring compliance assessment is done in accordance with DOE 450.1 through a quarterly deployment cycle. TLDs are deployed at a 1 meter height, adhering to the guidance of *Environmental Regulatory Guide for Radiological Effluent Monitoring and Environmental Surveillance* (U.S. DOE 1991).

For the purposes of reporting comparisons, data is reported as a "standard 90-day quarter," with the dose reported in millisievert (mSv; 1 mSv = 100 mrem).

Monitoring Results

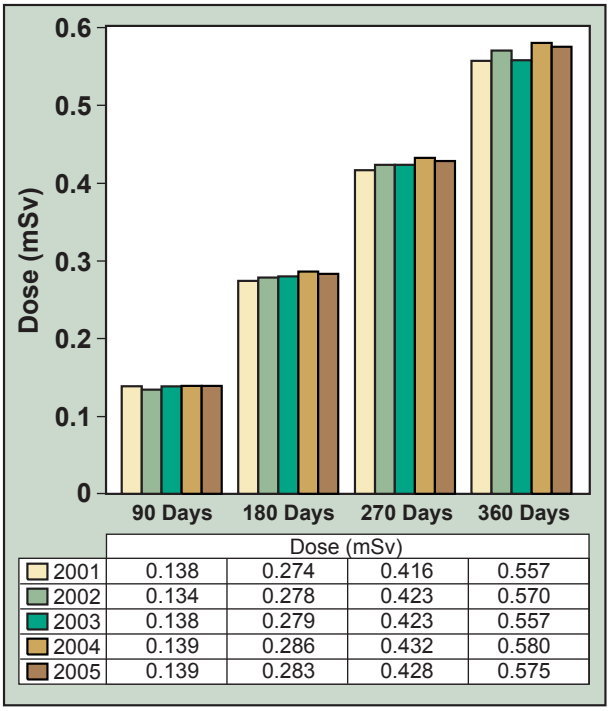
In **Figures 6-7** through **6-10**, the quarterly average cumulative doses in mSv for 2005 are presented for the Livermore site, the Livermore Valley, on-site at Site 300 and off-site at Site 300 along with five years of quarterly doses from 2001 to 2005.

Figure 6-7 illustrates the average cumulative dose for the Livermore site perimeter for successive 90 day periods for the entire year. The graph indicates a stable trend in the site-wide annual dose when compared to previous years. Similar trends are evident when comparing the data of **Figures 6-8**, **6-9** and **6-10**.



	Dose (mSv)			
2001	0.140	0.277	0.420	0.560
2002	0.134	0.279	0.423	0.571
2003	0.140	0.280	0.422	0.557
2004	0.139	0.286	0.425	0.573
2005	0.141	0.287	0.436	0.580

Figure 6-7. Livermore site perimeter quarterly cumulative dose (mSv), 2001 through 2005

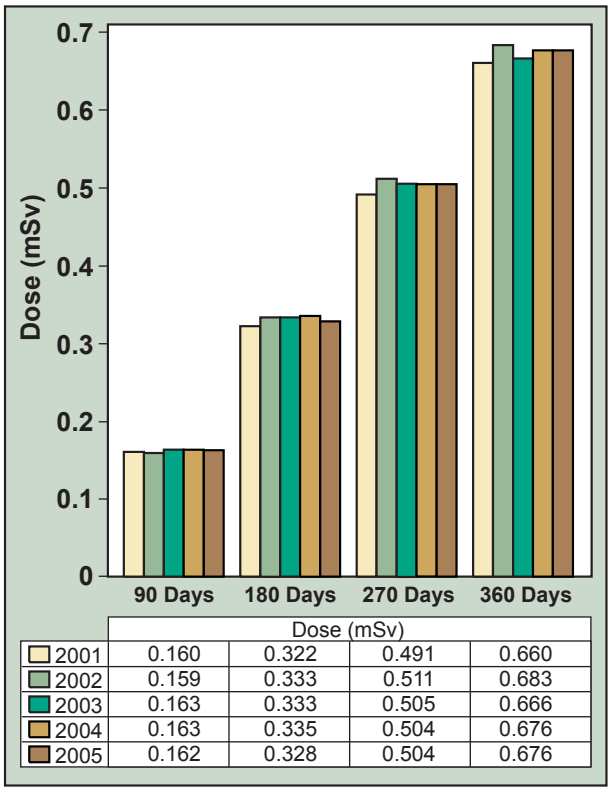


	Dose (mSv)			
2001	0.138	0.274	0.416	0.557
2002	0.134	0.278	0.423	0.570
2003	0.138	0.279	0.423	0.557
2004	0.139	0.286	0.432	0.580
2005	0.139	0.283	0.428	0.575

Figure 6-8. Livermore Valley quarterly cumulative dose (mSv), 2001 through 2005

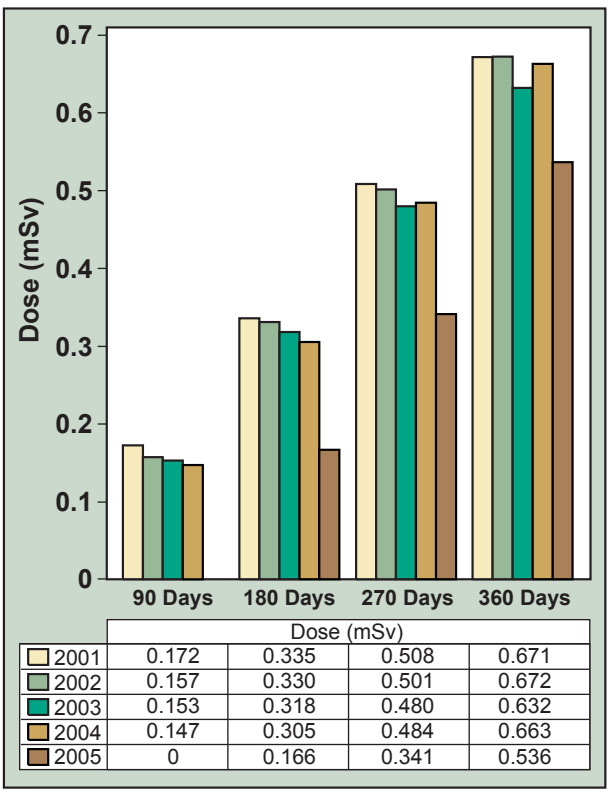
Tabular data for each individual sampling location illustrate the quarterly variation (see file "Ch6 Ambient Radiation" provided on the report CD). Missing data are due to lost or damaged samples.

Site variation is largely due to changes in the local distribution of the radon flux as a product of decay from the uranium and thorium series on some small level and from changes in the cosmic radiation flux. For example, when the data for the Livermore site perimeter are examined for the 5 year period by location (**Figure 6-11**), the local site variation is readily observed. Similar variability is seen within the other location groups (**Figures 6-12** and **6-13**).



	Dose (mSv)			
2001	0.160	0.322	0.491	0.660
2002	0.159	0.333	0.511	0.683
2003	0.163	0.333	0.505	0.666
2004	0.163	0.335	0.504	0.676
2005	0.162	0.328	0.504	0.676

Figure 6-9. Site 300 on-site quarterly cumulative dose (mSv), 2001 through 2005



	Dose (mSv)			
2001	0.172	0.335	0.508	0.671
2002	0.157	0.330	0.501	0.672
2003	0.153	0.318	0.480	0.632
2004	0.147	0.305	0.484	0.663
2005	0	0.166	0.341	0.536

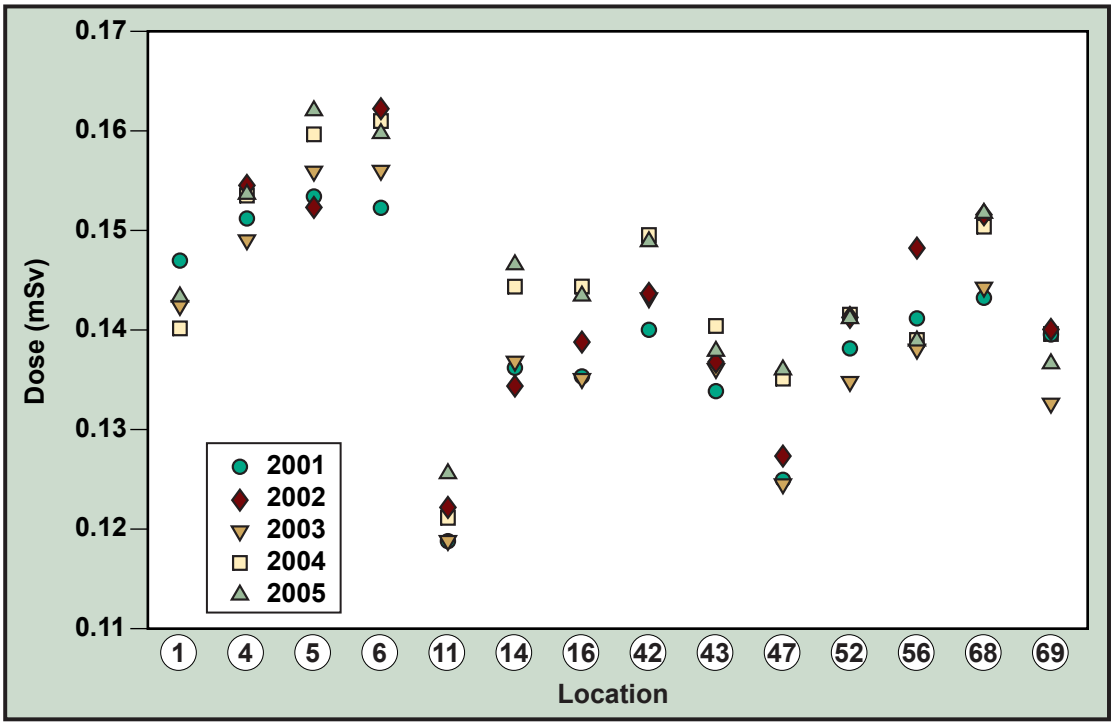
Note: First quarter data not available due to lost or damaged samples, which also affects the cumulative dose.

Figure 6-10. Site 300 environs quarterly cumulative dose (mSv), 2001 through 2005

Environmental Impact from Laboratory Operations

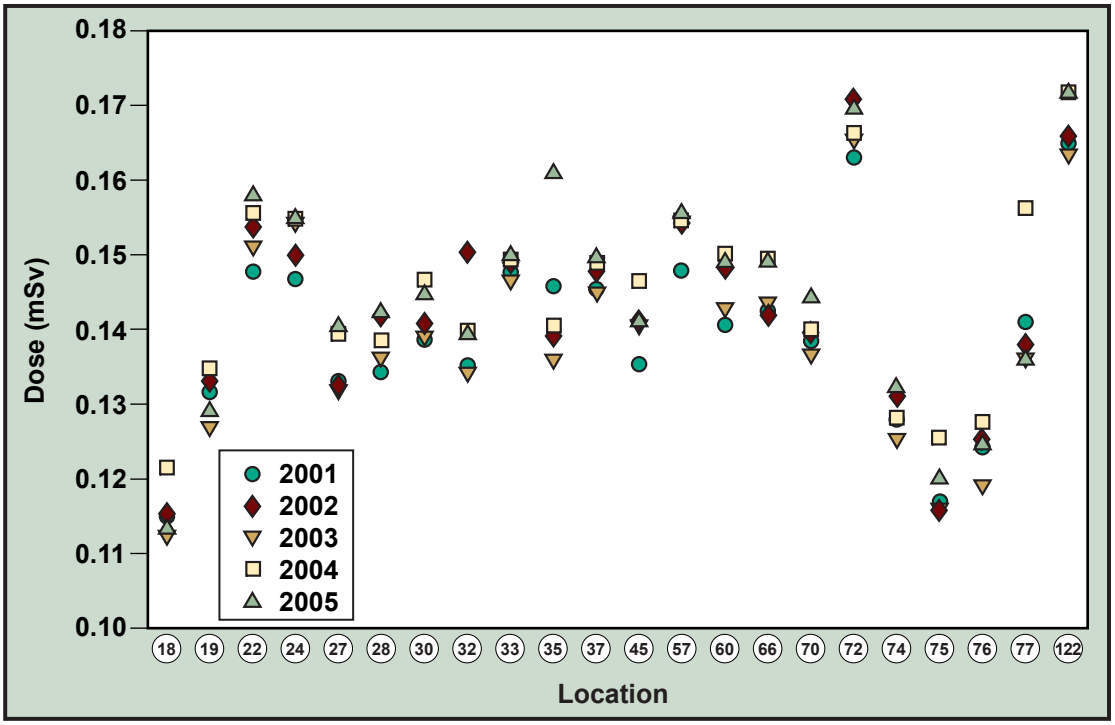
There is no evidence to conclude that there is any environmental impact or increase in direct gamma radiation as a result of LLNL operations as measured by the TLD network for the year 2005. The radiation dose trends remain annually consistent for each sample site. Although some locations have had anomalous annual values in comparison to the long term trend for these locations, the trends would have continued at those sample sites had there been any contamination affecting the dose at that site. This is the most important reason for long term trend analysis and why local spurious excursions such as at location 35 (**Figure 6-12**) are not considered alarming.

As depicted in **Figure 6-14**, the annual average gamma radiation dose from 2001 to 2005 is statistically equivalent and shows no discernible impact due to operations conducted at LLNL.



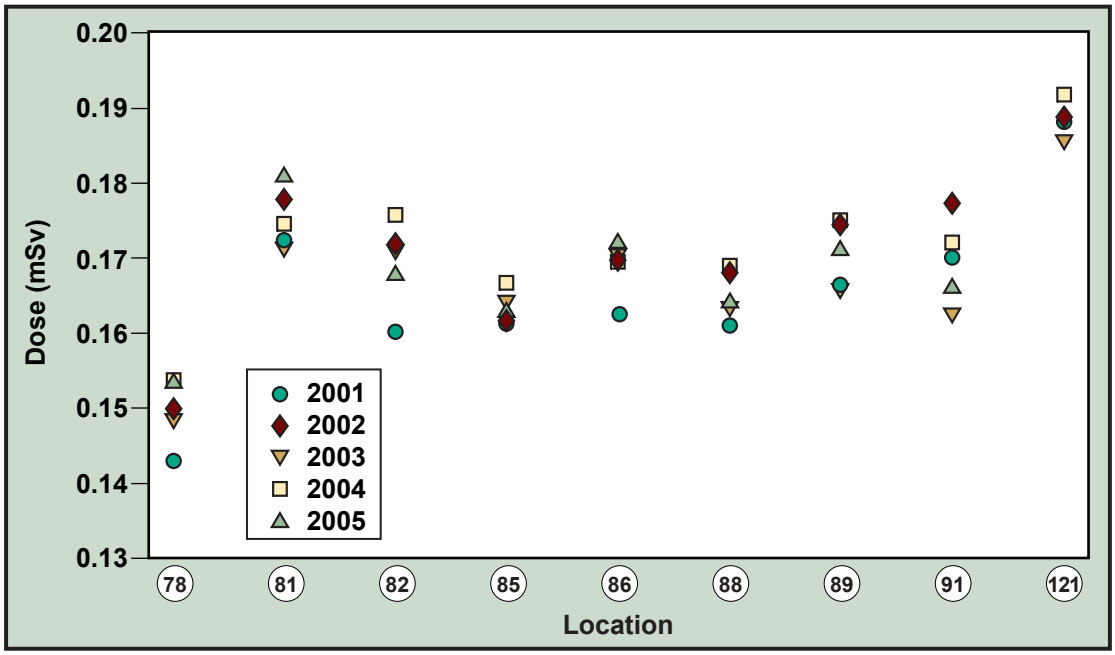
Note: See **Figure 6-1** for locations.

Figure 6-11. Livermore site perimeter annual average dose by location from 2001 to 2005



Note: See **Figure 6-2** for locations.

Figure 6-12. Livermore Valley annual average dose by location from 2001 to 2005



Note: See **Figure 6-3** for locations.

Figure 6-13. Site 300 annual average dose by location from 2001 to 2005

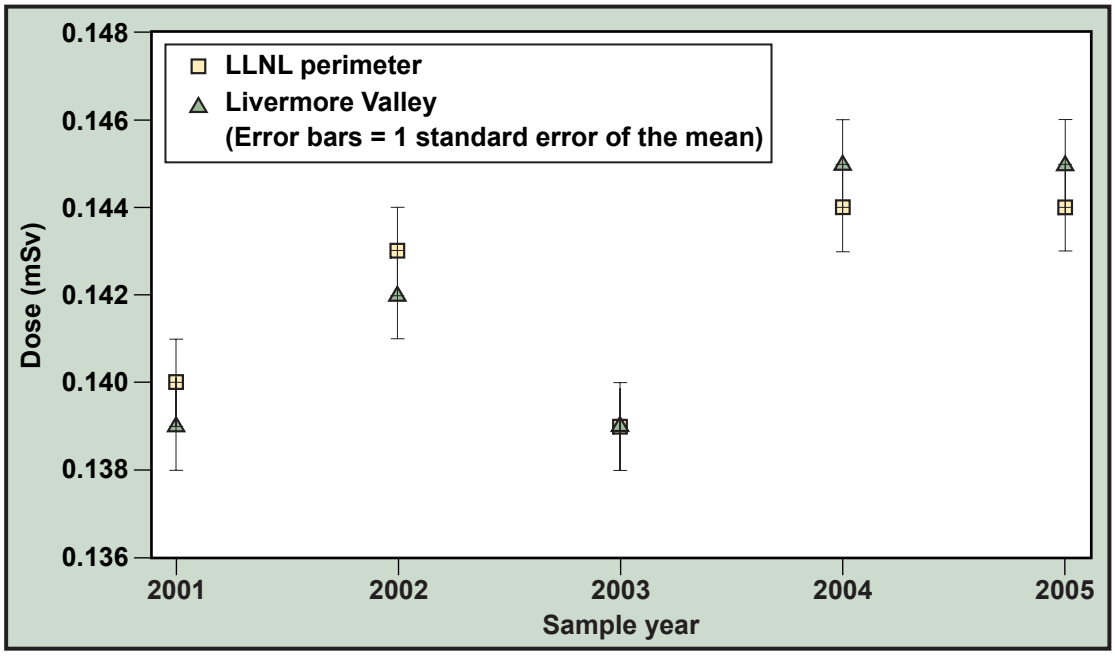


Figure 6-14. Annual average gamma radiation dose comparison for Livermore site and the Livermore Valley

Special Status Wildlife and Plants

Special status wildlife and plant monitoring efforts at LLNL are focused on species considered to be rare, threatened, or endangered. This includes species listed under the California or Federal Endangered Species Acts; species considered of concern by the California Department of Fish and Game, and the U.S. Fish and Wildlife Services (USFWS); and species that require inclusion in National Environmental Policy Act (NEPA) and California Environmental Quality Act of 1970 (CEQA) documents.

Locations of species of particular interest are shown in **Figure 6-1** for the Livermore site and **Figures 6-15** and **6-16** for Site 300. A list of species known to occur at Site 300, including state and federally listed species, is found in Appendix C. (A similar list has not been prepared for the Livermore site.)

Five species that are listed under the federal or California endangered species acts are known to occur at Site 300: the California tiger salamander (*Ambystoma californiense*), California red-legged frog (*Rana aurora draytonii*), Alameda whipsnake (*Masticophus lateralis euryxanthus)*, valley elderberry longhorn beetle (*Desmocerus californicus dimorphus)*, and the large-flowered fiddleneck (*Amsinckia grandiflor*a). Although there are no recorded observations of the federally endangered San Joaquin kit fox (*Vulpes macrotis mutica*) at Site 300, this species is known to have occurred in the adjacent Carnegie and Tracy Hills areas (USFWS 1998). Because of the proximity of known observations of San Joaquin kit fox to Site 300, it is necessary to consider potential impacts to San Joaquin kit fox during activities at Site 300. California threatened Swainson's Hawks (*Buteo swainsoni*) and California endangered Willow Flycatchers (*Empidonax traillii*) have been observed at Site 300, but breeding habitat for these species does not occur at Site 300. The California red-legged frog is also known to occur at the Livermore site.

Several other species that are considered rare or otherwise of special interest by the federal and state governments also occur at Site 300 and the Livermore site. These species include California Species of Special Concern, California Fully Protected Species, federal Species of Concern, species that are the subject of the federal Migratory Bird Treaty Act, and those species included in the California Native Plant Society's (CNPS's) *Inventory of Rare and Endangered Plants* (CNPS 2001). In particular, monitoring programs have been developed at Site 300 for the Tricolored Blackbird (*Agelaius tricolor*), a California species of special concern, and at the Livermore site for the White-tailed Kite (*Elanus leucurus*), a California fully protected species.

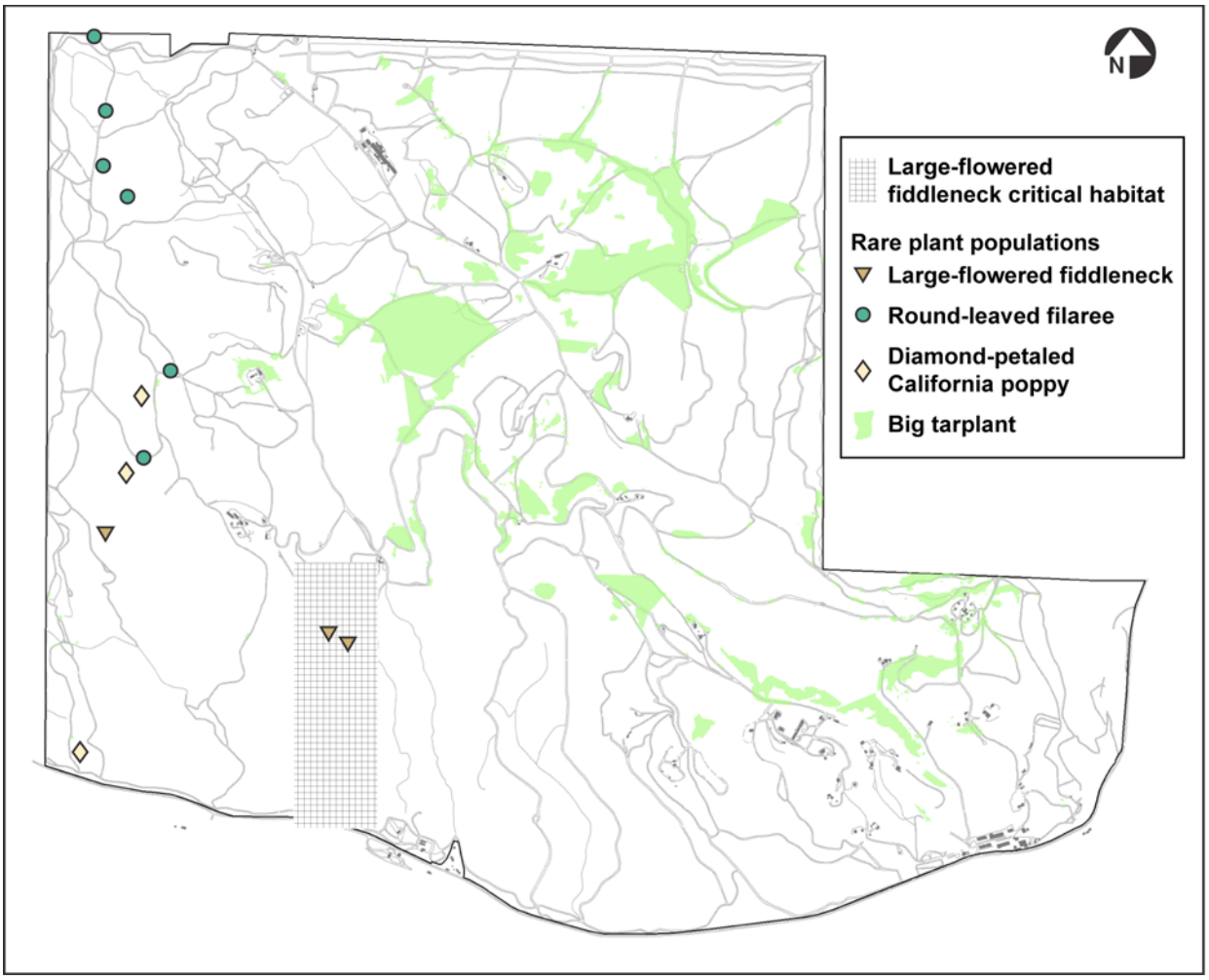


Figure 6-15 Distribution of federal and California threatened and endangered plants, Site 300, 2005

Including the federally endangered large-flowered fiddleneck, four rare plant species and four uncommon plant species are known to occur at Site 300. Three of these species, the large-flowered fiddleneck, the big tarplant (*Blepharizonia plumosa*, also known as *Blepharizonia plumosa* subsp *plumosa*), and the diamond-petaled poppy (*Eschscholzia rhombipetala*), are included in the CNPS List 1B (CNPS 2001). These species are considered rare and endangered throughout their range. An additional species, the round-leaved filaree (*Erodium macrophyllum*) is currently included on CNPS List 2 (CNPS 2001). This list includes species that are rare or endangered in California and elsewhere. The four uncommon plant species, the gypsum-loving larkspur (*Delphinium gypsophilum* subsp. *gypsophilum*), California androsace (*Androsace elongata* subsp. *acuta*), stinkbells (*Fritillaria agrestis*), and hogwallow starfish (*Hesperevax caulescens*), are all included on the CNPS List 4 (CNPS 2001). List 4 plants are uncommon enough to warrant

monitoring, but are not considered rare. Past surveys have failed to identify any rare plants on the Livermore site (Preston 1997, 2002).

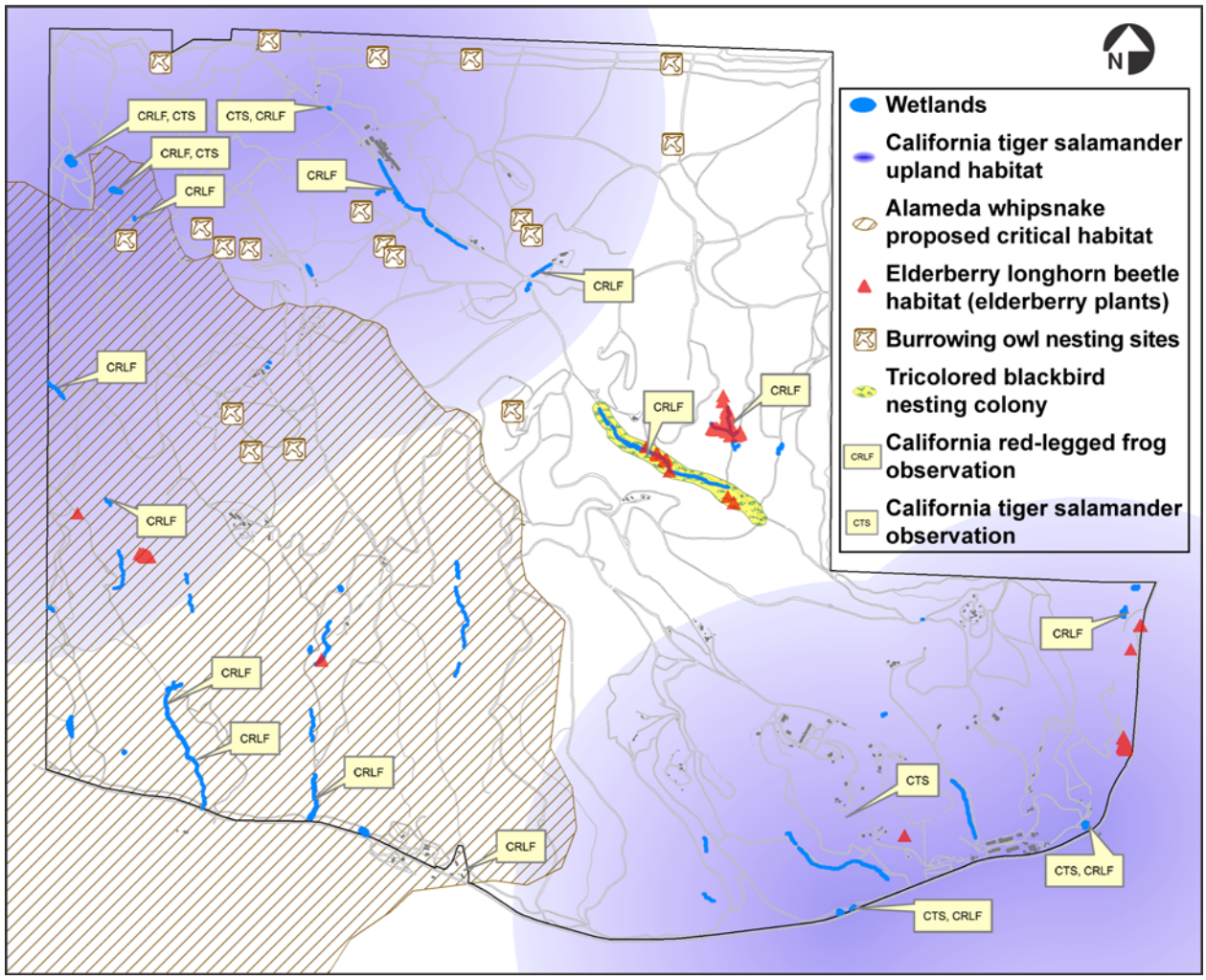


Figure 6-16 Distribution of federal and California threatened and endangered wildlife, Site 300, 2005

The following sections describe results from LLNL special status wildlife and plant studies and surveys. For an estimate of LLNL's dose to biota, see the "Special Topics on Dose Assessment" section in Chapter7.

Compliance Activities

Arroyo Las Positas

In 2000, LLNL began dredging sections of the Arroyo Las Positas to alleviate concerns about flooding of sensitive facilities within the Livermore site. No dredging was conducted in Arroyo Las Positas in 2005.

The Water Discharge Requirements for this project called for the implementation of a five-year Maintenance Impact Study (MIS) for this project. The final report for this MIS was submitted to the SFRWQCB in January 2006, and described monitoring completed between 2000 and 2005. The MIS included monitoring the status of three biological variables: California red-legged frog population, macro-invertebrate community, and wetland vegetation. (This monitoring was conducted in accordance with the 1997 and 1998 amended USFWS Biological Opinion for the Arroyo Las Positas Maintenance Project.)

Arroyo Seco

On June 10, 2005, the USFWS issued a biological opinion to DOE/NNSA for the Arroyo Seco Management Plan. The biological opinion for this project considers potential impacts to the California red-legged frog and the California tiger salamander. Although these species have not been observed at the project site, a biological assessment (BA) was prepared because there are multiple observations of these species 0.5 mile from the project site, and potential habitat for these species exists at the project site.

At the project site, Arroyo Seco is an intermittent stream, which typically receives water flow only after major rain events. The LLNL reach of Arroyo Seco occurs in an urban area. Public roads cross Arroyo Seco at the west and south boundaries of LLNL, and remnant orchards, LLNL structures, and landscaped areas occur above its banks. Prior to the implementation of the Arroyo Seco Management Plan, the channel of Arroyo Seco was deeply incised, and existing revetments were found in several locations. The banks of the stream were vegetated by a combination of ornamental and native riparian trees with an understory of annual grassland species.

The Arroyo Seco Management Plan was completed during the 2005 dry season. It included repairs to gully erosion around storm drain outfalls, installation of vegetated geogrids in eroding transition zones between existing gabion baskets and neighboring banks, and the addition of drop inlet structures to convey concentrated runoff down bank slopes at other gully erosion sites. In addition, the lower third of the LLNL reach of the Arroyo was realigned to increase the amount of meander in this area and decrease the slope of the creek banks. This involved constructing a new low flow channel and right and left in-channel terraces, and planting the channel terraces and bank slopes with native trees and shrubs.

LLNL was able to successfully implement the conservation and avoidance measures included in the Arroyo Seco Management Plan Biological Opinion. Although this project did not result in any direct impacts to California red-legged frogs or California tiger salamanders, it did result in a temporary decrease in the value of the habitat at the project site for California red-

legged frogs. As the native vegetation planted at the project site matures, it should shade portions of the channel and provide cover, thus improving the value of the habitat for California red-legged frogs. This project did not result in any significant temporary or long-term impacts to California tiger salamander habitat.

Habitat Enhancement Project

In late-August 2005, a habitat enhancement project was undertaken at Site 300 and, in accordance with the 2002 Biological Opinion, was implemented to compensate for habitat value loss from artificial wetlands created from discharges of blow down from cooling towers located at Buildings 865, 851, 827, and 801. These artificial wetlands were maintained with potable water when the blow down discharges were discontinued. Two areas within the Mid-Elk Ravine drainage were enlarged and deepened to create habitat pools where California red-legged frogs are known to occur and where pooling water features were limited in extent. The three primary goals of this effort were the creation of open water habitat (minimum of 0.012 acres), the protection of 1.86 acres of wetland and upland habitat, and the translocation of California red-legged frogs from the Building 865 wetland to the two new pools. In 2005, the first two goals were accomplished. The translocation of the California red-legged frog was conducted in February and March of 2006.

California Whipsnake

In 2002, LLNL began participating in a study, in cooperation with the USFWS and four other agencies, to determine the effects of prescribed burns on the federally threatened Alameda whipsnake. At Site 300, the Alameda whipsnake is classified as the California whipsnake (*Masticophis lateralis*) because it more closely resembles an intergrade between two species: Alameda whipsnake (*Masticpophis lateralis euryxanthus*) and the Chaparral whipsnake (*Masticophis lateralis lateralis*). In April 2002, the USFWS issued a biological opinion for this study that outlined the general conditions for conducting prescribed burns and gathering information about potential impacts to California whipsnakes. Through participation in this study, LLNL obtained USFWS approval to conduct prescribed burns necessary for Site 300 operation in areas that support California whipsnakes. The study area consists of a control site and a burn site that are vegetated by a mosaic of coastal scrub and annual grasslands. Baseline studies were conducted in spring and fall of 2002 and spring of 2003 at Site 300 and consisted of livetrapping California whipsnakes, recording the location of individuals, and marking the snakes for future identification.

There was a total of 18 California whipsnakes captures (9 at the control site and 9 in the burn site) during baseline monitoring in the spring and fall of

2002, and 12 captures (8 in the control site and 4 in the burn site) in the spring of 2003. A prescribed burn was conducted at the burn site in the summer of 2003, and the first season of post-burn monitoring was conducted in the fall of 2003. One California whipsnake was captured in the control site in the fall of 2003, and no California whipsnakes were captured in the burn site. Post-burn trapping of California whipsnakes continued in the spring and fall of 2004. In 2004, there was a total of 10 California whipsnake captures during spring trapping (6 in the control area and 4 in the burn area), and no California whipsnakes were captured during the fall trapping period. In 2005, a total of 8 California whipsnakes captures occurred during the spring trapping period (6 in the control area and 2 in the burn area). A wildfire that originated offsite in mid-July entered the Site 300 property and burned both whipsnake study areas. Effects of the burn will be evaluated during the 2006 trapping season. No trapping was conducted in the fall of 2005 due to previous low capture success rates. To date, no conclusions have been formulated about the effects of the Site 300 prescribed burns on California whipsnakes.

Class II Surface Impoundments

At Site 300, two interconnected Class II nonhazardous wastewater surface impoundments previously known to have been used by California tiger salamanders were removed. As mitigation for loss of suitable California tiger salamander habitat that occurred during the removal of these impoundments, a new pond was created in the northwest corner of Site 300, a remote area of the site. Construction of this new pond was completed successfully, and California tiger salamander activity at the previous location of the surface impoundments and the mitigation pond will be monitored in 2006.

Invasive Species Control Activities

Invasive species, including the bullfrog *(Rana catesbeiana)* and the largemouth bass *(Micropterus salmoides),* are a significant threat to the California red-legged frog at the Livermore site. The Drainage Retention Basin (DRB) was drained in 2000 and 2001 in an effort to eliminate bullfrog larvae. The Habitat Enhancement Pool portion of the DRB and the LLNL reach of Arroyo Las Positas were drained to control bullfrogs and largemouth bass in the fall of each year from 2002 through 2005. Adult bullfrogs and egg masses were also removed from the DRB during the bullfrog's breeding season (late spring to early fall). Two nighttime surveys for adult bullfrogs were conducted in the DRB in the summer of 2005. During these surveys, bullfrogs were identified by a qualified biologist and removed. In addition, 16 bullfrog egg masses were removed from the DRB during weekly surveys in 2005. These invasive species control measures were conducted under the 2002 amendment to the Arroyo Las Positas Maintenance Plan biological opinion.

Surveillance Monitoring

Wildlife

Nesting Bird Surveys

LLNL conducts nesting bird surveys to ensure LLNL activities comply with the Migratory Bird Treaty Act and do not result in impacts to nesting birds. White-tailed Kites, a California fully protected species, annually nest in the trees located along the north, east, and south perimeters of the Livermore site. LLNL staff surveyed potential White-tailed Kite nesting sites using binoculars or a spotting scope during the spring of 2005; two pairs of White-tailed Kites successfully fledged a total of eight young. Although White-tailed Kites are also known to occasionally nest at Site 300, site-wide kite surveys were not conducted at Site 300 in 2005 because the kites do not typically nest in areas where they may be affected by programmatic activities.

Avian Monitoring Program

An avian monitoring program, initiated in 2001 to obtain background information for the draft *Site-wide Environmental Impact Statement for the Continued Operation of Lawrence Livermore National Laboratory and Supplemental Stockpile Stewardship and Management Programmatic Environmental Impact Statement* (see Chapter 2 for more information on the environmental impact statement), was continued in 2005. A constant effort mist netting station was also established spanning Elk Ravine and Gooseberry Canyon at Site 300. Birds were captured using ten standard passerine mist nets once every ten days throughout the breeding season (May through August 2005). Birds captured in the mist nets were identified to species, banded, aged, sexed, measured, and weighed before being released. All of the species identified in these surveys are listed in Appendix C.

Rare Plants

LLNL conducted restoration and/or monitoring activities in 2005 for the four rare plant species known to occur at Site 300: the large-flowered fiddleneck, the big tarplant, the diamond-petaled poppy, and the round-leaved filaree. The results of this work are described in more detail in a biannual progress report (Paterson et al. 2005).

Large-Flowered Fiddleneck

The only federally protected plant species known to occur at Site 300 is the large-flowered fiddleneck (*Amsinckia grandiflora*), a federally listed and state listed endangered species. A 160-acre portion of Site 300 has been designated as critical habitat for this plant. This species is known to exist naturally in only two locations: at Site 300 in the *Amsinckia grandiflora* Reserve (the

Drop Tower native population) and on a nearby ranch. An additional population (the Draney Canyon native population) historically was known to occur in a remote canyon at Site 300. This population was extirpated during a landslide in the 1997/1998 rainy season. The Drop Tower native population contained no large-flowered fiddleneck plants in 2005, 3 plants in 2004, 5 plants in 2003, and 19 plants in 2002 (see **Figure 6-17**).

LLNL also established an experimental population of the large-flowered fiddleneck within the *Amsinckia grandiflora* Reserve at Site 300 starting in the early 1990s. The experimental population is divided into two subpopulations known as the flashing (FL) and fire frequency (FF) experimental populations. The size of the experimental population fluctuates as a result of seed bank enhancement efforts conducted in this population. The two experimental subpopulations combined contained 127 large-flowered fiddleneck plants in 2005, 768 plants in 2004, 119 plants in 2003 and 67 plants in 2002 (see **Figure 6-17**).

LLNL is also beginning to see results in the long-term fire frequency experiment begun in 2001. The native perennial grass *Poa secunda* is most abundant in plots that are burned annually. Previous research shows that large-flowered fiddleneck is more successful in plots dominated by *P. secunda* compared to plots dominated by exotic annual grasses (Carlsen et al. 2000), but early results from the fire frequency experiment show that large-flowered fiddleneck is more abundant in the unburned control plots dominated by dense annual grasses than in the burned plots. Data from plots burned at an intermediate frequency are not yet available.

While LLNL has uncovered some clues to the successful restoration of large-flowered fiddleneck populations and continues to work to sustain the existing experimental and native populations, the reasons for the sharp declines in this population in recent years are still unclear. Seed bank enhancement efforts are more successful when plots are netted and seeds from greenhouse or controlled environment experiments are used, but the resulting plants can be small and produce little seed. LLNL can promote the establishment of a native perennial grassland with prescribed burns, but seed predation is quite high in these burned areas.

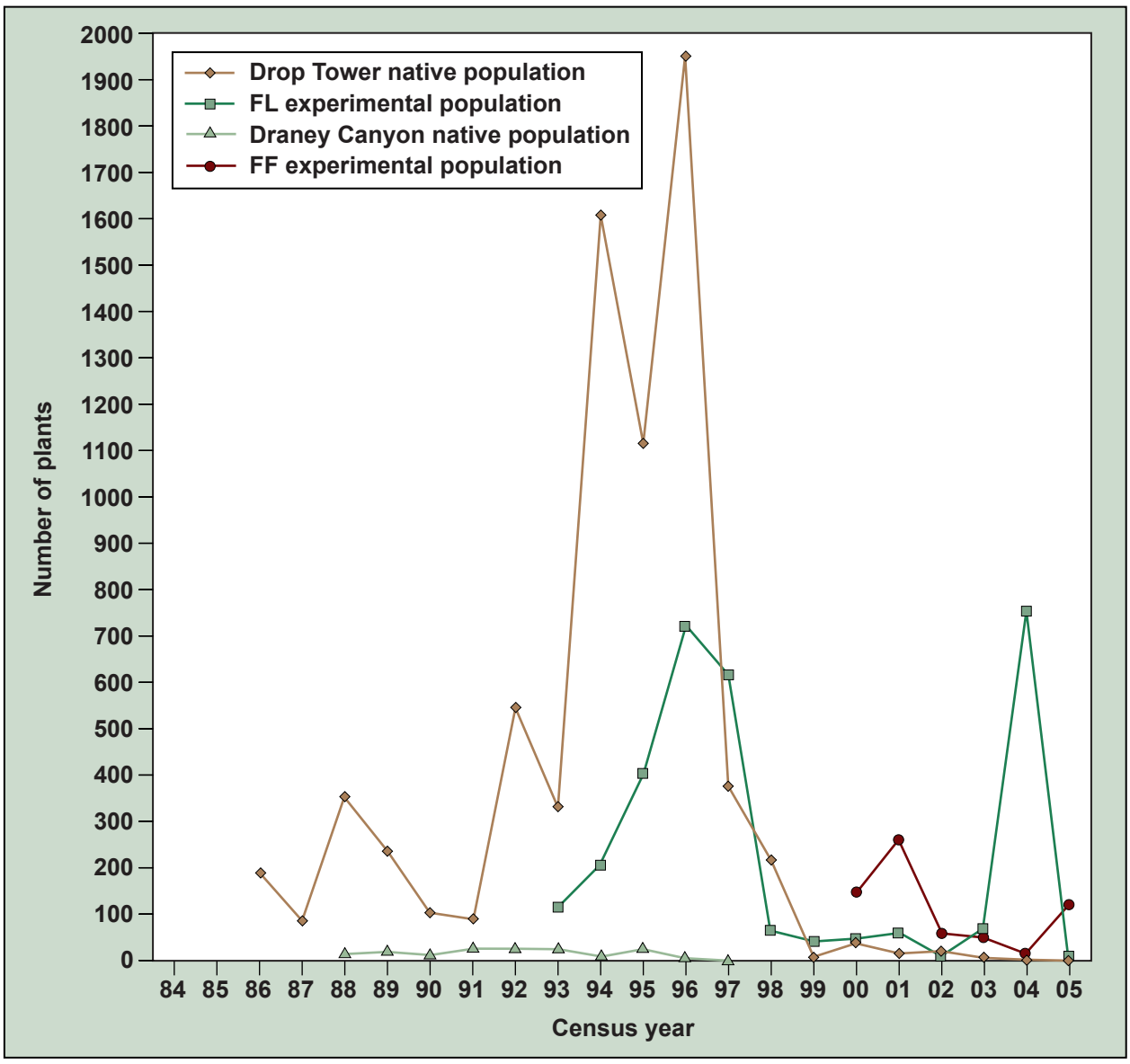


Figure 6-17. Number of large-flowered fiddleneck plants in Site 300 experimental and native populations, 1986–2005

Big Tarplant

The distribution of big tarplant was mapped using a handheld GPS in September and October 2005. The big tarplant was widely distributed at Site 300 in 2005 compared to 2006.

In 2005 a prescribed burn was conducted in the area surrounding Building 801 in an attempt to boost the big tar plant population in that area. This area had not burned for several years and the previous large population in this area had become quite small. (Since the construction of the contained firing facility at Building 801, it has not been necessary to conduct prescribed

burns in this area.) Prior to the Building 801 burn transects were established to measure big tarplant seedling recruitment. Using these transects and GPS mapping, LLNL hopes to determine if the 2005 prescribed burn had a positive impact of the big tarplant population.

Diamond-Petaled California Poppy

There are currently three populations of diamond-petaled California poppy (*Eschscholzia rhombipetala)* known to occur at Site 300. Although this species is not listed under the federal or California endangered species acts, it is extremely rare and is currently known to only occur at Site 300 and one additional location in San Luis Obispo County. A census of the three Site 300 populations was conducted in March and April 2005, during which time LLNL recorded the size and location of each diamond-petaled poppy plant and the composition of the vegetation community in which this species occurs.

In 2005, a total of 906 diamond-petaled California poppies were found at Site 300. The most recently discovered population, site 3, contained by far the largest number of diamond-petaled California poppies (853 plants) in 2005. Diamond-petaled California poppy populations at site 1 (28 plants) and site 2 (25 plants) have continued to be very small in recent years.

Round-Leaved Filaree

Six small populations of round-leaved filaree are known to occur at Site 300. All populations occur in the northwestern portion of Site 300. This species thrives in the disturbed soils of the annually graded fire trails at Site 300. Of the six populations, four occur on fire trails. During the spring of 2005, the extent of the six Site 300 populations was mapped using a handheld GPS and the size of each population was estimated. These six populations were estimated to contain approximately 3650 round-leaved filaree plants.

July 19, 2005, Wildfire

On July 19, after the spring census of Site 300 rare plants was completed, a wildfire occurred at Site 300. This fire included all diamond petaled California poppy, large-flowered fiddleneck, and round-leaved filaree populations that occur at Site 300. This fire occurred at a time when these spring flowering annual plants had already set seed, so the fire is not likely to result in direct impacts to these plants. Results of the spring 2006 census will help in determining the impacts of this wildfire.

Environmental Impacts on Special Status Wildlife and Plants

Through monitoring and compliance activities in 2005, LLNL has been able to avoid most impact to special status wildlife and plants. LLNL activities, including the Arroyo Seco management plan, did not negatively impact

California red-legged frogs at the Livermore site. In the Livermore site population of California red-legged frogs, breeding decreased in 2005 compared to previous years although this decrease is not linked directly to LLNL activities. Invasive species continue to be the largest threat to California red-legged frogs at the Livermore site. In 2005 LLNL expanded efforts to educate LLNL employees on the problems of introducing any species to LLNL. LLNL also continued its bullfrog eradication program in 2005.

At Site 300, the habitat enhancement pools were created in Elk Ravine as mitigation of impact to California red-legged frog habitat that will occur as a result of decreased cooling water discharge. Construction was completed successfully and California red-legged frog use of the created wetlands will be monitored in 2006.

Large-flowered fiddleneck and diamond-petaled California poppy populations are located in remote areas of Site 300 away from programmatic impacts. Four of the six Site 300 round-leaved filaree populations are located in annually graded fire trails. In these fire trail populations, round-leaved filaree is restricted to the areas that are disturbed by grading. This disturbance appears to benefit the species and is not considered a negative impact. Although rare elsewhere, big tarplant is widely distributed throughout Site 300. Although individual big tarplants were disturbed by LLNL activities, including fire trail grading and well drilling, these impacts affected only a very small fraction of the Site 300 tarplant population and are not considered to be significant to this species.

Radiological Dose Assessment

CHAPTER 7

Cynthia L. Conrado
S. Ring Peterson

Introduction

Lawrence Livermore National Laboratory (LLNL) assesses potential radiological doses to biota, off-site individuals, and the population residing within 80 km of either the Livermore site or Site 300. These potential doses are calculated to determine the impact of LLNL operations, if any, on the general public and the environment, and to demonstrate compliance with regulatory standards set by the U.S. Department of Energy (DOE) and the U.S. Environmental Protection Agency (EPA).

Releases of radioactive material to air are the major source of public radiological exposure from LLNL operations, and radiological monitoring of stack air effluent and ambient air (Chapter 4) represents a significant monitoring effort. In addition to ambient air and stack monitoring there is monitoring of radioactivity in a variety of media including soil, sediment, vegetation, wine and measured environmental gamma radiation (Chapter 6). Monitoring at LLNL also includes the sampling of wastewaters, storm water and groundwater as well as rainfall and local surface water (Chapter 5). Releases to these water systems are not sources of direct exposures to the public because they are not directly consumed.

Measurements of radiological releases to air and modeling the dispersion of the released radionuclides determine LLNL's dose to the public. Because LLNL is a DOE facility, it is subject to the requirements of Title 40 of the Code of Federal Regulations (CFR) Part 61 Subpart H, the National Emissions of Hazardous Air Pollutants (NESHAPs). LLNL uses the EPA Clean Air Act Assessment Package-1988 (CAP88-PC) computer model in

demonstrating site compliance with NESHAPs regulations. This dose code evaluates the four principal exposure pathways: ingestion, inhalation, air immersion, and irradiation by contaminated ground surface.

The major radionuclides measured by LLNL in 2005 that contribute to individual and collective dose were tritium at the Livermore site and three uranium isotopes (uranium-234, uranium-235, and uranium-238) at Site 300. All radionuclides measured at the Livermore site and Site 300 were used to assess dose to biota.

This chapter summarizes detailed radiological dose determinations and identifies trends over time while placing them in perspective with natural background and other sources of radiation exposure.

Releases of Radioactivity from LLNL Operations

Radiological releases to air are estimated by three principal means: continuous monitoring of stack effluent at selected facilities (described in Chapter 4); routine surveillance ambient air monitoring for radioactive particles and gases, both on and off LLNL property (also described in Chapter 4); and radioactive material usage inventories. Of these three approaches, stack monitoring provides the most definitive characterization. Beginning in 2003, the extent of reliance on usage inventories declined in favor of increased utilization of ambient air monitoring data (see the "Compliance Demonstration for Minor Sources" section below).

Radiation Protection Standards

The release of radionuclides from operations at LLNL and the resultant radiological impact to the public are regulated by both the U.S. Department of Energy (DOE) and the U.S. Environmental Protection Agency (EPA).

The primary DOE radiation standards for protection of the public are 1 millisievert per year (1 mSv/y) (which equals 100 millirem per year [100 mrem/y]) whole-body effective dose equivalent (EDE) for prolonged exposure of a maximally exposed individual in an uncontrolled area and 5 mSv/y (500 mrem/y) EDE for occasional exposure of this individual. (EDEs and other technical terms are discussed in *Supplementary Topics on Radiological Dose* [available on report CD] and defined in the glossary of this report.) These limits pertain to the sum of the EDE from external radiation and the committed 50-year EDE from radioactive materials ingested or inhaled during a particular year that may remain in the body for many years.

The EPA's radiation dose standard for members of the public limits the EDE to 100 μSv/y (10 mrem/y) for air emissions. EPA regulations specify not only the allowed levels, but also the approved methods by which airborne emissions and their impacts must be evaluated. With respect to all new or modified projects, NESHAPs compliance obligations define the requirements to install continuous air effluent monitoring and to obtain EPA approval before the startup of new operations. NESHAPs regulations require that any operation with the potential to produce an annual average off-site dose greater than or equal to 1 μSv/y (0.1 mrem/y), taking full credit for emission-abatement devices such as high-efficiency particulate air (HEPA) filters, must obtain EPA approval prior to the startup of operations. This same calculation, but without taking any credit for emission abatement devices, determines whether or not continuous monitoring of emissions to air from a project is required. These requirements are spelled out in LLNL's *Environment, Safety, and Health (ES&H) Manual*, Document 31.2, "Radiological Air Quality Compliance."

Air Dispersion and Dose Models

Computational models are needed to describe the transport and dispersion in air of contaminants and the doses to exposed persons via all pathways. CAP88-PC is the DOE and EPA mandated computer code used by LLNL to compute radiological individual or collective (i.e., population) dose resulting from radionuclide emissions to air. This code operates on a personal computer and is relatively easy to use and understand.

CAP88-PC uses a modified Gaussian plume equation to estimate the average dispersion of radionuclides released from up to six collocated sources (Parks 1992). Input parameters used in the model include radionuclide type, emission rate in curies per year, and stack parameters, such as stack height, inside diameter and exit velocity. A site-specific wind parameter file is prepared annually from meteorological data collected by LLNL. The mathematical models and equations used in CAP88-PC are described in *User's Guide for CAP88-PC, Version 1.0* (Parks 1992).

Calculated doses include the four principal exposure pathways: internal exposures from inhalation of air and ingestion of foodstuff and drinking water (only for tritium), and external exposures through irradiation from contaminated ground and immersion in contaminated air. Dose is calculated as a function of radionuclide, pathway, spatial location, and body organ.

In addition, CAP88-PC provides the flexibility to adjust agricultural parameters (e.g., numbers of milk cows per km^2) and the fractions of contaminated foods ingested. For the 2005 evaluation, LLNL took advantage of this capability and used updated assumptions for agricultural and food

source parameters for CAP88-PC (see Larson et al. 2006). This is the second year these updated assumptions have been used. Furthermore, an improved tritium model (NEWTRIT; Peterson and Davis 2002) that uses air concentrations predicted by CAP88-PC to address the dose from releases of HT and the dose from organically bound tritium was again employed to compare with the tritium model in CAP88-PC.

Identification of Key Receptors

Dose is assessed for two types of receptors. First is the dose to the site-wide maximally exposed individual (SW-MEI; defined below) member of the public. Second is the collective or "population" dose received by people residing within 80 km of either of the two LLNL sites.

The SW-MEI is defined as the hypothetical member of the public at a single, publicly accessible location who receives the greatest LLNL-induced EDE from all sources at a site. For LLNL to comply with NESHAPs regulations, the LLNL SW-MEI must not receive an EDE as great or greater than 100 μSv/y (10 mrem/y) from releases of radioactive material to air. Public facilities that could be the location of the SW-MEI include schools, churches, businesses, and residences. This hypothetical person is assumed to remain at one location 24 hours per day, 365 days per year, continuously breathing air having the predicted or observed radionuclide concentration, and consuming a specified fraction of food and drinking water[1] that is affected by the same predicted or observed air concentration caused by releases of radioactivity from the site. Thus, the SW-MEI dose is not received by any actual individual and is a conservative estimate of the highest possible dose that may be received by any member of the public.

At the Livermore site, the SW-MEI in 2005 was located at the UNCLE Credit Union, about 10 m outside the controlled eastern perimeter of the site. This location lies 957 m from the Tritium Facility (Building 331), in an east-northeast direction (the typical prevailing wind direction). At Site 300, the SW-MEI occupied a position on the south-central boundary of the site bordering the Carnegie State Vehicular Recreation Area, 3170 m south-southeast of the firing table at Building 851. These SW-MEI locations are depicted in **Figure 7-1**.

[1] This is calculated for tritium only.

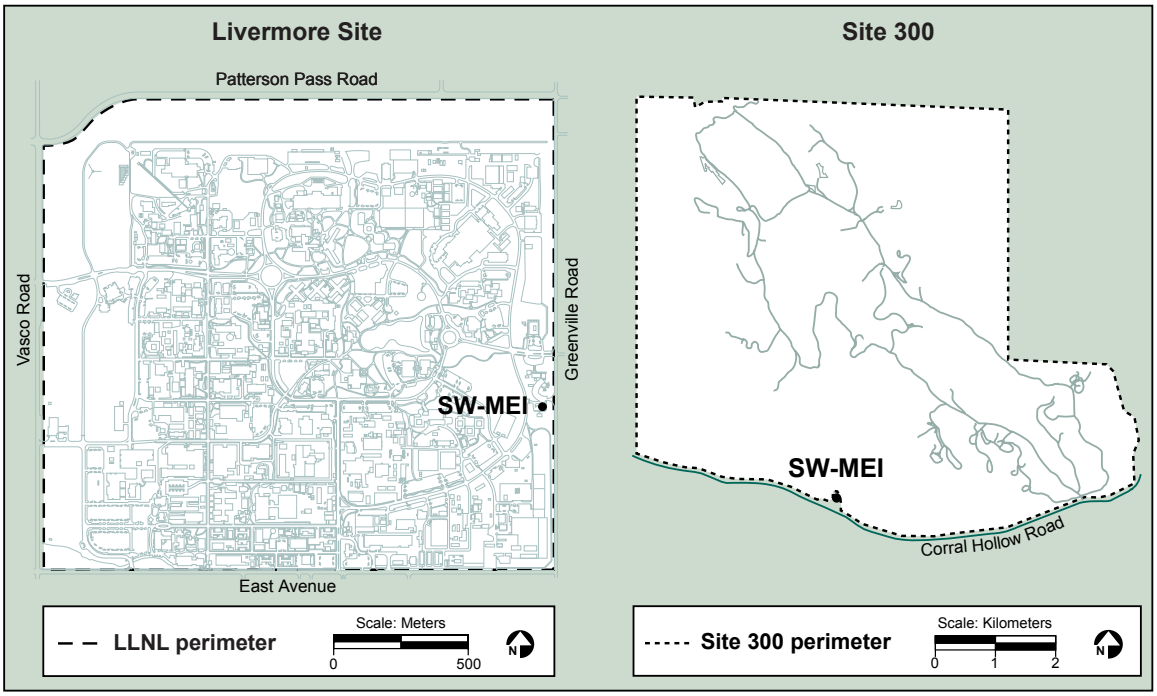


Figure 7-1. Location of the site-wide maximally exposed individual (SW-MEI) at the Livermore site and Site 300, 2005

Results of 2005 Radiological Dose Assessment

This section summarizes the doses to the most exposed public individuals from LLNL operations in 2005, shows the temporal trends compared with previous years, presents the potential doses to the populations residing within 80 km of either the Livermore site or Site 300, and places the potential doses from LLNL operations in perspective with doses from other sources.

Total Dose to Site-Wide Maximally Exposed Individuals

The total dose to the SW-MEI from Livermore site operations in 2005 was 0.065 μSv/y (0.0065 mrem/y). Of this, the dose attributed to diffuse emissions (area sources) totaled 0.038 μSv (0.0038 mrem) or 59%; the dose due to point sources was 0.027 μSv (0.0027 mrem) or 41% of the total. The point source dose includes Tritium Facility elemental tritium gas (HT) emissions modeled as tritiated water (HTO), as directed by EPA Region IX. Using NEWTRIT rather than CAP88-PC to calculate the dose for tritium emissions reduced the tritium component of the total dose from 0.059 μSv (0.0059 mrem) to 0.052 μSv (0.0052 mrem).

The total dose to the Site 300 SW-MEI from operations in 2005 was 0.18 µSv (0.018 mrem). Point source emissions from firing table explosives experiments totaled 0.088µSv (0.0088 mrem) accounting for 48% of the dose, while 0.094 µSv (0.0094 mrem), or about 52%, was contributed by diffuse emission sources.

Table 7-1 shows the facilities or sources that accounted for nearly 100% of the dose to the SW-MEI for the Livermore site and Site 300 in 2005. Although LLNL has nearly 150 sources with potential for releasing radioactive material to air according to NESHAPs prescriptions, most are very minor. Nearly the entire radiological dose to the public each year from LLNL operations comes from no more than six sources. In April 2003, EPA granted LLNL permission to use surveillance monitoring in place of inventory-based modeling to account for dose contributions from the numerous minor sources. This procedure was implemented for the third time in assessing 2005 operations (see also *LLNL NESHAPs 2005 Annual Report* [Larson et al. 2006]).

Table 7-1. List of facilities or sources whose combined emissions accounted for nearly 100% of the SW-MEI doses for the Livermore site and Site 300 in 2005

Facility (source category)	CAP88-PC dose (µSv/y)[a]	CAP88-PC percentage contribution to total dose
Livermore site		
Building 331 stacks (point source)	0.026[b]	40
Building 612 Yard (diffuse source)	0.020[b]	31
Building 331 outside (diffuse source)	0.012[b]	18
Southeast Quadrant soil resuspension (diffuse source)	0.0061	9
Site 300		
Soil resuspension (diffuse source)	0.094	52
Building 851 Firing Table (point source)	0.088[c]	48

a 1 µSv = 0.1 mrem

b When LLNL's NEWTRIT model is used in place of CAP88-PC's default tritium model, the dose for the Building 331 stacks is reduced to approximately 86% of the value shown, and doses for the Building 612 Yard and Building 331 outside are reduced to 89% of the values shown.

c The Building 851 Firing Table had fewer explosive experiments in 2005 than in previous years.

Dominant radionuclides at the two sites were the same as in recent years. Tritium accounted for about 91% of the Livermore site's calculated dose. At Site 300, practically the entire calculated dose was due to the isotopes uranium-238, uranium-235, and uranium-234 from depleted uranium.

Regarding pathways of exposure, the relative significance of inhalation and ingestion depends on the assumptions made about the origin of food consumed and the predominant radionuclide contributing to dose. For individual doses calculated for tritium, the ingestion dose accounts for slightly more than the inhalation dose, approximately 53% and 47%, respectively. For uranium, the inhalation pathway dominates: 97% by the inhalation pathway versus 3% via ingestion. LLNL doses from air immersion and ground irradiation are negligible for both tritium and uranium.

The trends in dose to the SW-MEI from emissions at the Livermore site and Site 300 over the last 15 years are shown in **Table 7-2**. The general pattern, particularly over the last decade, shows year-to-year fluctuations around a low dose level, staying at or below about 1% of the federal standard. The SW-MEI dose estimates are intentionally conservative, predicting potential doses that are higher than actually would be experienced by any member of the public.

Doses from Unplanned Releases

There were no unplanned atmospheric releases of radionuclides to the atmosphere at the Livermore site or Site 300 in 2005.

Collective Dose

Collective dose for both LLNL sites was calculated out to a distance of 80 km in all directions from the site centers using CAP88-PC. Population centers affected by LLNL emissions include the nearby communities of Livermore and Tracy; the more distant metropolitan areas of Oakland, San Francisco, and San Jose; and the San Joaquin Valley communities of Modesto and Stockton. Within the 80 km outer distance specified by DOE, there are 7.1 million residents included for the Livermore site collective dose determination, and 6.2 million for Site 300. Population data files (distribution of population with distance and direction) used for the present report are based on the LandScan Global Population 2001 Database (Dobson et al. 2000).

The CAP88-PC result for potential collective dose attributed to 2005 Livermore site operations was 0.0117 person-Sv (1.17 person-rem); the corresponding collective EDE from Site 300 operations was 0.0171 person-Sv (1.71 person-rem). These values are both within the normal range of variation seen from year to year.

Table 7-2. Doses (μSv/y)[a] calculated for the sitewide maximally exposed individual (SW-MEI) for the Livermore site and Site 300, 1990 to 2005

Year	Total dose	Point source dose	Diffuse source dose
Livermore site			
2005	0.065[b]	0.027[b]	0.038
2004	0.079[b]	0.021[b]	0.058
2003	0.44[b]	0.24[b]	0.20
2002	0.23[b]	0.10[b]	0.13
2001	0.17[b]	0.057[b]	0.11
2000	0.38[b]	0.17[b]	0.21
1999	1.2[b]	0.94[b]	0.28
1998	0.55[b]	0.31[b]	0.24
1997	0.97	0.78	0.19
1996	0.93	0.48	0.45
1995	0.41	0.19	0.22
1994	0.65	0.42	0.23
1993	0.66	0.40	0.26
1992	0.79	0.69	0.10
1991	2.34	—[c]	—[c]
1990	2.40	—[c]	—[c]
Site 300			
2005	0.18	0.088	0.094
2004	0.26	0.25	0.0086
2003	0.17	0.17	0.0034
2002	0.21	0.18	0.033
2001	0.54	0.50	0.037
2000	0.19	0.15	0.037
1999	0.35	0.34	0.012
1998	0.24	0.19	0.053
1997	0.20	0.11	0.088
1996	0.33	0.33	0.0045
1995	0.23	0.20	0.03
1994	0.81	0.49	0.32
1993	0.37	0.11	0.26
1992	0.21	0.21	—[d]
1991	0.44	0.44	—[d]
1990	0.57	0.57	—[d]

a 1 μSv = 0.1 mrem
b The dose includes HT emissions modeled as HTO as directed by EPA Region IX.
c Diffuse source doses were not calculated for the Livermore site for 1990 and 1991.
d No diffuse emissions were evaluated at Site 300 before 1993.

Although collective doses from LLNL operations are tiny compared with doses from natural background radiation, they may be high compared with other DOE facilities due to large populations within 80 km of the sites. However, a large dose to a small number of people is not equivalent to a small dose to many people, even though the collective dose may be the same. Given that the population centers potentially affected by LLNL operations are distant from both the Livermore site and Site 300, the collective doses from LLNL operations are better described by breaking them down into categories of dose received by individuals in the population affected. The breakdown (or disaggregation) of collective dose by the level of the individual dose in **Table 7-3** demonstrates that about 94% of the population receives less than 0.01 µSv/y (1 µrem/y).

Table 7-3. Collective dose broken down by level of individual doses, 2005

Individual dose range (µSv/y) [a]	Collective dose person-Sv/y[b]	Percent total collective dose
Livermore site		
0.01 to 0.1	0.0000517	0.444%
0.001 to 0.01	0.00716	61.0%
0.0001 to 0.001	0.00339	28.9%
0.00001 to 0.0001	0.00114	9.71%
Total[c]	0.0117	100%
Site 300[d]		
0.01 to 0.1	0.00107	6.25%
0.001 to 0.01	0.0106	62.0%
0.0001 to 0.001	0.00507	29.6%
0.00001 to 0.0001	0.000336	1.96%
0.00000001 to 0.00001	0.0000334	0.195%
Total	0.0171	100%

a 1 µSv = 0.1 mrem
b 1 person-Sv = 100 person-rem
c An additional 0.05% of the population received a dose less than 1×10^{-5} µSv.
d Dose from Building 851 Firing Table and Building 801A.

Doses to the Public Placed in Perspective

As a frame of reference to gauge the size of these LLNL doses, **Table 7-4** compares them to average doses received in the United States from exposure to natural background radiation and other sources. Collective doses from LLNL operations in 2005 are about 700,000 times smaller than ones from natural background radiation. The estimated maximum potential doses to

individual members of the public from operations at the two LLNL sites (combined) in 2005 are nearly 12,000 times smaller than ones received from background radiation in the natural environment.

Table 7-4. Comparison of background (natural and man-made) and LLNL radiation doses, 2005

Location/source	Individual dose[a] (μSv) [c]	Collective dose[b] (person-Sv) [d]
Livermore site sources		
Atmospheric emissions	0.065	0.0117
Site 300 sources		
Atmospheric emissions	0.18	0.0171
Other sources[e]		
Natural radioactivity[f,g]		
Cosmic radiation	300	2,130
Terrestrial radiation	300	2,130
Internal (food consumption)	400	2,840
Radon	2,000	14,200
Medical radiation (diagnostic procedures)[f]	530	3,760
Weapons test fallout[f]	10	71
Nuclear fuel cycle	4	28

a For LLNL sources, this dose represents that experienced by the SW-MEI.
b The collective dose is the combined dose for all individuals residing within an 80-km radius of LLNL (approximately 7.1 million people for the Livermore site and 6.2 million for Site 300), calculated with respect to distance and direction from each site. The Livermore site population estimate of 7.1 million people was used to calculate the collective doses for "Other sources".
c 1 μSv = 0.1 mrem
d 1 person-Sv = 100 person-rem
e From National Council on Radiation Protection and Measurements (NCRP 1987a,b)
f These values vary with location.
g This dose is an average over the U.S. population.

Special Topics on Dose Assessment

Compliance Demonstration for Minor Sources

From 1991 through 2002, LLNL demonstrated compliance for minor sources through a labor-intensive inventory and modeling process. The dose consequences to the public for these sources were 8 to 20 orders of magnitude below the regulatory standard of 100 μSv/y (10 mrem/y) and did not justify the level of effort expended in accounting for them. To better allocate resources, LLNL made a request to EPA, pursuant to the NESHAPs regulations, to use existing ambient air monitoring to demonstrate compliance for minor sources. This request was made in March 2003 and

granted by EPA in April 2003. This report marks the third year that LLNL is demonstrating NESHAPs compliance for minor sources by comparing measured ambient air concentrations at the location of the SW-MEI to concentration limits set by the EPA in Table 2, Appendix E of 40 CFR 61. The radionuclides for which the comparison is made are tritium and plutonium-239+240 for the Livermore site SW-MEI and uranium-238 for the Site 300 SW-MEI. At the Livermore site, the average of the monitoring results for locations VIS and CRED represent the SW-MEI. At Site 300, the minor source that has the potential to have a measurable effect is the resuspension of depleted uranium contaminated soil. Because this is a diffuse source, the average of the results for all monitoring locations at the site are used to represent the SW-MEI.

The Table 2, Appendix E of 40 CFR 61 standards and the measured concentrations at the SW-MEI are presented in SI units in **Table 7-5**. As demonstrated by the calculation of the fraction of the standard, LLNL-measured concentrations for tritium and plutonium-239+240, and uranium-238 in air are 0.0023 or less than the health protective standard for these radionuclides.

Table 7-5. Mean concentrations of radionuclides of concern at the location of the SW-MEI in 2005

Location	Nuclide	EPA concentration standard (Bq/m^3)	Detection limit (approximate) (Bq/m^3)	Mean measured concentration (Bq/m^3)	Measured concentration as a fraction of the standard
Livermore SW-MEI	Tritium	56	0.037	$0.048^{(a)}$	8.7×10^{-4}
Livermore SW-MEI	Plutonium-239	7.4×10^{-5}	1.9×10^{-4}	$8.9 \times 10^{-9(b)}$	1.2×10^{-4}
Site 300 SW-MEI	Uranium -238	3.1×10^{-4}	1.1×10^{-4}	$7.0 \times 10^{-7(c)}$	2.3×10^{-3}

Note: 1 Bq = 2.7×10^{-11} Ci

a The tritium value includes contributions from the Tritium Facility, Building 612 Yard, DWTF Stack and Area Source, and Building 331 Waste Accumulation Area.

b The mean measured concentration for plutonium is less than the detection limit; only 3 of the 24 values comprising the mean were measured detections.

c The ratio for the mean uranium-235 and uranium-238 concentrations for 2005 is 0.005 which is less than 0.00726, the ratio of these isotopes for naturally occurring uranium. This results in approximately 57% of the resuspension being attributable to naturally occurring uranium and 43% being attributable to depleted uranium.

Estimate of Dose to Biota

Although mankind is protected from excess radiation dose by the methods outlined in this chapter, biota are not necessarily protected because of different exposure pathways (e.g., dose to a ground squirrel burrowing in contaminated soil). Thus LLNL calculates potential dose to biota from LLNL operations using the DOE guidance document, "DOE Standard: A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota" (U.S. DOE 2002), and the RAD-BCG (Biota Concentration Guides) Calculator

(Version 2) in an Excel spreadsheet. Limits on absorbed dose to biota are 10 mGy/d (1 rad/d) for aquatic animals and terrestrial plants, and 1 mGy/d (0.1 rad/d) for terrestrial animals. Radionuclides contributing to dose to biota were americium-241, cesium-137, tritium, plutonium-239 (analyzed as plutonium-239 and also as a surrogate for gross alpha), thorium-232, uranium-235, and uranium-238; in addition, gross beta was represented by strontium-90.

In the RAD-BCG Calculator, each radionuclide in each medium (soil, sediment, surface water) is assigned a derived concentration limit. For each concentration entered in the spreadsheet, a fraction of the derived concentration limit for that radionuclide is automatically calculated; the fractions are summed for each medium. For aquatic and riparian environments, if a concentration for water is entered, the calculator automatically assigns an expected concentration to the sediment, and vice versa.

For aquatic and riparian animals, the sum of the fractions for water exposure is added to the sum of the fractions for sediment exposure. Similarly, fractions for water and soil exposures are summed for terrestrial animals. If the sums of the fractions for the aquatic and terrestrial systems are both less than 1 (i.e., the dose to the biota does not exceed the screening limit), the site has passed the screening analysis, and biota are assumed protected.

In the LLNL assessment, the maximum concentration of each radionuclide measured in soils, sediments, and surface waters during 2005, no matter whether measured on the Livermore site, in the Livermore Valley, or at Site 300, was entered into the screening calculation. This approach will result in an assessment that is unrealistically conservative, given that the maximum concentrations in the media are scattered over a very large area, and no plant or animal could possibly be exposed to them all. Other assumptions increase the possibility that the estimated dose will be conservative. For example, while only gross alpha and gross beta are measured in water, it is assumed that gross alpha is represented by plutonium-239 and gross beta by strontium-90 to assure maximum dose. Furthermore, although biota would most likely live in and near permanent bodies of water (i.e., surface water), measurements of storm water runoff were used for the assessment because much higher concentrations of radionuclides are measured in runoff than in surface waters. Finally, when measurements were available for both runoff and sediment, the value that gave the highest fraction of the BCG was used.

In 2005, using the assumptions above, the aquatic system failed the screening test. This was due entirely to very high concentrations of gross alpha (from an upstream location) and gross beta (from a downstream location) in the runoff of February 15 at Site 300. These values were due to high levels of total suspended solids (TSS) in the runoff samples rather

than to concentrations in the runoff water, and thus they can be rejected as not representing runoff. (Suspended sediments at Site 300 contain significant quantities of naturally occurring uranium and its daughter decay products that account for elevated levels of gross alpha and beta activities.). The sum of the fractions for the aquatic system, after the highest runoff concentrations were rejected, was 0.280, and the sum for the terrestrial system was 0.035. These results for the aquatic system are similar to those in 2002, 2003, and 2004. The sum of the fractions for the terrestrial system is similar to previous years.

A less artificial assessment of dose to aquatic biota from LLNL operations can be made using runoff or release concentrations from the Drainage Retention Basin (DRB) combined with sediment concentrations from the East Settling Basin (ESB). Sediment samples are not collected in the DRB, and water is ephemeral at the ESB. Nevertheless, concentrations may be expected to be similar given that water drains through the ESB to the DRB. Using these concentrations in the RAD-BCG Calculator, the sum of the fractions for aquatic exposure is 0.034, which is about 12% of the fraction derived from the ultraconservative approach. It is clear that dose to biota from LLNL operations is below levels of regulatory concern.

Modeling Dose from Tritium — Comparison of Approaches

Dose predictions can vary due to different modeling approaches and assumptions. Because tritium has been and continues to be the principal radionuclide released to air in Livermore site operations (from a public dose standpoint), a comparison of potential doses for 2005, calculated from different approaches, is presented.

Since 1986, LLNL has calculated doses from releases of HTO (or total tritium modeled as HTO) to the atmosphere using the regulatory model CAP88-PC (since 1992) or its predecessor, AIRDOS-EPA. The dose calculated with AIRDOS-EPA or CAP88-PC uses source terms for the principal tritium sources at the site. As well, since 1979, using bulk transfer factors (**Table 7-6**) derived from equations in the Nuclear Regulatory Commission's (NRC) Regulatory Guide 1.109 (U.S. NRC 1977), LLNL has calculated potential ingestion doses from measured concentrations in vegetation (Chapter 6) and drinking water (Chapter 5), as well as doses from inhalation (Chapter 4). Both CAP88-PC and Regulatory Guide 1.109 only account for dose from HTO. More conceptually accurate assessments should account for dose from releases of HT and from ingestion of organically bound tritium (OBT); if OBT is ignored, ingestion dose may be underestimated by up to a factor of two (ATSDR 2002). In recent years, another model, NEWTRIT (Peterson and Davis 2002), has been used to estimate inhalation and ingestion doses from releases of both HT and HTO; the ingestion dose

accounts for both HTO and OBT. NEWTRIT uses observed or predicted air concentrations as input.

Table 7-6. Bulk transfer factors used to calculate inhalation and ingestion doses from measured concentrations in air, vegetation, and potential drinking water

Doses in μSv	Bulk transfer factors[a] times observed mean concentrations
Inhalation and skin absorption	0.21 x concentration in air (Bq/m^3) (See Chapter 4)
Drinking water	0.013 x concentration in drinking water (Bq/L) (See Chapter 5)
Food Ingestion	0.0049 x concentration in vegetation (Bq/kg) (See Chapter 6); (factor obtained by summing contributions of 0.0011 for vegetables, 0.0011 for meat and 0.0027 for milk)

a The derivation for these bulk transfer factors can be found in Appendix C of *Environmental Report 2002* (Sanchez et al. 2003).

Hypothetical tritium doses predicted at VIS, the on-site location of air tritium and vegetation sampling (see **Figure 4-1**), using the three modeling approaches are compared in **Table 7-7**. All predictions were made for a hypothetical person living 100% of the time adjacent to the air tritium monitor at VIS and eating 100% locally grown food. Because the air tritium monitor can only sample for HTO, only HTO releases were used to calculate air tritium concentrations using CAP88-PC.

Table 7-7. Comparison of hypothetical doses (nSv/y) at the VIS air tritium monitoring location calculated from predicted and observed concentrations of HTO in air in 2005

	CAP88-PC (from predicted air concentrations)[a]	NRC 1.109 (from mean air, vegetation, and tap water[b] concentrations)	NEWTRIT (from mean air tritium concentrations)
Inhalation and skin absorption	22	9.9	11
Food ingestion (vegetables; milk; meat)	71; 44; 26	2.6; 6.5; 2.6	28; 18; 8.9
Drinking water	1.3	< 27[c]	4.7
Food ingestion dose	141	12	54
Total dose	164	< 49	70

a Doses from CAP88-PC are based on the sum of the predicted HTO concentrations at VIS for the Tritium Facility stacks (3.70×10^{-2} Bq/m^3), the Building 612 Yard (3.48×10^{-2} Bq/m^3), and the Building 331 area source (8.14×10^{-3} Bq/m^3), the DWTF stack (1.07×10^{-3} Bq/m^3) and DWTF area source (8.14×10^{-4} Bq/m^3).

b Tap water is measured on the Livermore site but not at the VIS location.

c All tap waters measured for tritium in 2005 were below the limit of detection.

The dose comparison shows about a factor of about 3.5 between the lowest (NRC 1.109) and highest (CAP88-PC) dose predictions, each of which is based on valid assumptions. Differences are primarily due to predicted (0.0818 Bq/m^3) versus observed (0.0470 Bq/m^3) air concentrations and

assumptions about intake rates and dose coefficients (see Appendix C of *Environmental Report 2002* [Sanchez et al. 2003]). When predicted air concentrations drive the doses, doses are normally higher than when observed air and vegetation concentrations drive the results. The total dose from CAP88-PC is the highest, as expected, and the NEWTRIT dose is within a factor of 2.4 of the CAP88-PC dose.

A more realistic, but still highly conservative, set of assumptions about the lifestyle of the hypothetical member of the public residing at the VIS monitor location (**Table 7-8**) lowers the annual dose from tritium to as low as about 25% of the lowest dose in **Table 7-7**, even while including tiny potential doses from other dose pathways.

Table 7-8. Doses for the tritium exposure of an individual residing at the VIS location in 2005, based on observed HTO-in-air concentrations and using plausible but conservative assumptions (as indicated)

Source of dose	Annual dose (nSv/y)	Assumption
Inhalation and skin absorption	4.1	Breathes air at VIS 16 hours a day, all year at a lower rate than CAP88 or NEWTRIT
Ingesting food, including OBT	7.4	Raises and eats 25% homegrown leafy vegetables, fruit vegetables, fruits and root crops, no homegrown milk, beef, pork, or grain but 12 kg/y homegrown chickens and 20 kg/y homegrown eggs. Assume the feed for the chickens is 50% homegrown; chickens drink water from outdoor pans at 50% air moisture.
Drinking water	[5.9][a]	Drinks 440 L/y of well water at average concentration of California groundwater
Drinking wine, including OBT	1.6	Drinks one liter bottle of Livermore Valley wine each week at the mean concentration for 2005
All sources	13[a]	

a Drinking water dose is not included in a realistic estimate of the dose impacts of LLNL releases of tritium to the atmosphere because Livermore drinking water is unaffected by LLNL operations. Nevertheless, inclusion of a drinking water dose demonstrates that the dose attributable to LLNL is not much different than background, especially given that all doses shown include background.

Environmental Impact

The annual radiological doses from all emissions at the Livermore site and Site 300 in 2005 were found to be well below the applicable standards for radiation protection of the public, in particular the NESHAPs standard. This standard limits to 100 μSv/y (10 mrem/y) the EDE to any member of the public arising as a result of releases of radioactive material to air from DOE facilities. Using an EPA-mandated computer model and actual LLNL

meteorology appropriate to the two sites, the potential doses to the LLNL SW-MEI members of the public from operations in 2005 were:

- Livermore site: 0.065 μSv (0.0065 mrem)—41% from point-source emissions, 59% from diffuse-source emissions. The point source emissions include gaseous tritium modeled as tritiated water vapor for compliance purposes, as directed by EPA Region IX.
- Site 300: 0.18 μSv (0.018 mrem)—48% from explosive experiments, which are classified as point-sources, 52% from diffuse-source emissions.

As noted earlier, the major radionuclides accounting for the doses were tritium at the Livermore site and the three isotopes in depleted uranium (uranium-234, uranium-235, and uranium-238) at Site 300. The only significant exposure pathway contributing to dose from LLNL operations was release of radioactive material to air, leading to doses by inhalation and ingestion.

The collective EDE attributable to LLNL operations in 2005 was estimated to be 0.0117 person-Sv (1.17 person-rem) for the Livermore site and 0.0171 person-Sv (1.71 person-rem) for Site 300. These doses include potentially exposed populations of 7.1 million people for the Livermore site and 6.2 million people for Site 300 living within a distance of 80 km from the site centers.

The doses to the SW-MEI, which represent the maximum doses that could be received by members of the public resulting from Livermore site and Site 300 operations in 2005, were 0.07% and 0.18%, respectively, of the federal standard and were more than 16,000 times smaller than the dose from background radiation. The collective doses from LLNL operations in 2005 were about 700,000 times smaller than those caused by natural radioactivity in the environment.

Potential doses to aquatic and terrestrial biota from LLNL operations were assessed and found to be well below DOE screening dose limits.

In conclusion, potential radiological doses from LLNL operations were well below regulatory standards and were very small compared with doses normally received from natural background radiation sources, even though highly conservative assumptions were used in the determinations of LLNL doses. These maximum credible doses to the public indicate that LLNL's use of radionuclides had no significant impact on public health during 2005.